

**MAKERERE**



**UNIVERSITY**

**A MODEL COMMERCIALIZATION FRAMEWORK FOR  
TECHNOLOGICAL INNOVATIONS IN UGANDA**

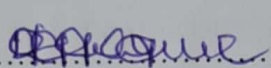
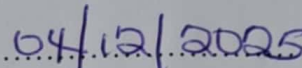
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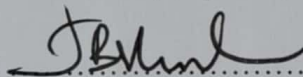
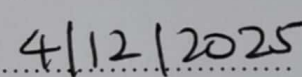
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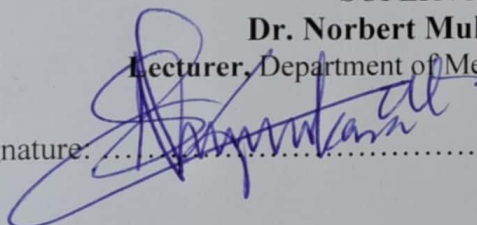
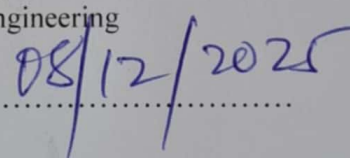
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**A Research Thesis Submitted to the Directorate of Research and Graduate  
Training in Partial Fulfillment of the Requirements for the Award of the Degree  
of Doctor of Philosophy of Makerere University, Kampala, Uganda**

**December, 2025**

**DECLARATION**

I hereby declare to the best of my knowledge that the work presented in this research thesis is my original work, done under the guidance of my supervisors, and has never been submitted to any university for the award of any degree.

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## **DEDICATION**

This thesis is dedicated to my dear wife, Peace Nakitto Jjagwe, and our children, Israel Jjagwe, Ivanna Nabachwa, Isabel Gwokyalya, Ivonne Nambatya, and Christopher Buyungo.

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## LIST OF ACRONYMS

CVD	-	Commercialization Valley of Death
EFA	-	Exploratory Factor Analysis
FDI	-	Foreign Direct Investment
GDP	-	Gross Domestic Product
GERD	-	Gross Expenditure on Research and Development
GII	-	Global Innovation Index
GMOs	-	Grants Management Offices
GOU	-	Government of Uganda
ICT	-	Information and Communication Technology
IP	-	Intellectual Property
IPRs	-	Intellectual Property Rights
ITDT	-	Innovation, Technology Development, and Transfer
MDAs	-	Ministries, Departments and Agencies
MFPEd	-	Ministry of Finance, Planning and Economic Development
MSI	-	Millenium Science Initiative
NDP	-	National Development Plan
NGO	-	Non-Government Organization
NIS	-	National Innovation System
OECD	-	Organization for Economic Cooperation and Development
PPP	-	Public Private Partnership
R&D	-	Research and Development
R&I	-	Research and Innovation
ROI	-	Return On Investment
SDGs	-	Sustainable Development Goals
SMEs	-	Small Medium Enterprises
SPAR-4-SLR	-	Scientific Procedures and Rationales for Systematic Literature Review
SPSS	-	Statistical Package for Social Scientists
STEM	-	Science, Technology, Engineering and Mathematics
STI	-	Science, Technology, and Innovation
STI-OP	-	Science, Technology and Innovation Secretariat-Office of the President
TAI	-	Technology Achievement Index
TAL	-	Technology Achievement Lifecycle
TL	-	Technology Lifecycle
TRIPS	-	Trade-Related Aspects of Intellectual Property Rights
TRL	-	Technology Readiness Level
TTOs	-	Technology Transfer Offices
TVD	-	Technology Valley of Death
UIRI	-	Uganda Industrial Research Institute
UNCST	-	Uganda National Council for Science and Technology
URSB	-	Uganda Registration Services Bureau
VCs	-	Venture Capitalists

## ABSTRACT

Innovation commercialization drives economic growth, prosperity, and sustainable development in Uganda. The Government of Uganda (GOU) has invested significantly in research, innovation, and development. Despite these efforts, challenges persist in translating innovations into commercially viable products and services. Scientists, researchers, and innovators often lack a structured approach to effective commercialization, and the existing literature lacks an integrative framework. This study aimed to elucidate a comprehensive framework for innovation commercialization by integrating strategies and measures at the firm, market, and policy levels. The research identifies key barriers and drivers affecting innovation commercialization and proposes actionable solutions to enhance the process in Uganda. The study employed a mixed-methods approach, integrating both quantitative and qualitative research methodologies. Data collection involved a review of key policy documents, key informant interviews, focus group discussions, and consultative meetings with researchers, innovators, and technopreneurs. Additionally, direct observations of innovation and commercialization processes within technology-driven enterprises were conducted. Interviews were conducted with technopreneurs, researchers, innovators, incubation managers, industry stakeholders, and government officials to gather insights into the factors influencing innovation commercialization. The study assessed commercialization barriers and drivers at the firm, market, and policy levels, leading to the development of targeted strategies and measures. The findings underscore the critical role of the National Innovation System (NIS) in facilitating interaction and learning among key stakeholders in Uganda's innovation ecosystem. Challenges such as fragmented ecosystems, inadequate support infrastructure, and insufficient financial mechanisms hinder the efficiency of research and innovation institutions. The study introduces a model commercialization framework and identifies the key determinants of successful commercialization, including firm-level capabilities, market-driven product awareness, industry dynamics, and policy-related factors. The study emphasizes the need for support mechanisms and recommends policy reforms to foster a vibrant market for technological innovations in Uganda. A multifaceted approach is proposed, incorporating investments in research and development (R&D) infrastructure, market access initiatives, and regulatory enhancements. Addressing structural barriers such as weak institutional support, limited financial access, and a lack of coordination among innovation actors is essential to bridge the commercialization gap. Strengthening talent exchange programs, developing regional knowledge value chains, and prioritizing institutional reforms are key to improving commercialization efficiency. To enhance the commercialization of innovations in Uganda, it is recommended to strengthen the NIS to improve collaboration and knowledge sharing among key actors; establish sustainable financial mechanisms to support innovation commercialization; enhance regulatory frameworks to create an enabling policy environment; expand R&D infrastructure to facilitate technology development and market readiness; and promote strategic partnerships to enhance market access and commercialization opportunities.

**Keywords:** Commercialization Drivers and Barriers, Model Commercialization Framework, National Innovation System, Research and Development, R&D Funding and Investment, Technological Innovations, Uganda.

## LIST OF PUBLICATIONS AND CONFERENCE PRESENTATIONS

This thesis is based on a compilation of seven papers published or in the process of being published in peer-reviewed journals and conference proceedings.

- I. Jjagwe, R., Kirabira, J. B., Mukasa, N. & Okure, M. (2024), "National innovation system for resilience, transformation and sustainable development in Uganda: contextual analysis of the factors, actors and associated linkages," *International Journal of Innovation Science*. <https://doi.org/10.1108/IJIS-09-2023-0197>
- II. Jjagwe, R., Kirabira, J. B. & Mukasa, N. (2024). Innovation and Commercialization Characteristics of Techno-Business Firms in Uganda: An Overview of Firm Processes, Strategies, and Challenges. *East African Journal of Interdisciplinary Studies*, 7(1), 278-296. <https://doi.org/10.37284/eajis.7.1.2148>
- III. Jjagwe, R., Kirabira, J. B. & Mukasa, N. (2024). Contribution of R&D grants and investment to the commercialization of innovations in Uganda: Lessons from UNCST a science granting council. *African Journal of Science, Technology, Innovation and Development*, 16(7), 1003–1022. <https://doi.org/10.1080/20421338.2024.2406157>
- IV. Jjagwe, R., Kirabira, J.B., Mukasa, N. & Amany, L. (2024). The drivers and barriers influencing the commercialization of innovations at research and innovation institutions in Uganda: a systemic, infrastructural, and financial approach. *J Innov Entrep* **13**, 78. <https://doi.org/10.1186/s13731-024-00435-y>
- V. Jjagwe, R., Kirabira, J. B. & Mukasa, N. (2024). Firm-specific, market-centric and policy-related determinants of ‘commercialization valley of death’ encountered by techno-business firms in Uganda. Proceedings of the 6<sup>th</sup> *AfricaLics International Research Conference*, November 13 - 15, 2024, University of Ilorin, Nigeria. [https://africalics.org/wp-content/uploads/6th\\_Research\\_Conference\\_Nigeria\\_Proceedings.pdf](https://africalics.org/wp-content/uploads/6th_Research_Conference_Nigeria_Proceedings.pdf)  
  
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- VI. Jjagwe, R., Kirabira, J. B., & Mukasa, N. Nurturing technopreneurship: bridging the commercialization valley of death among Ugandan researchers, innovators, and techno-business firms. *Journal of Innovation and Entrepreneurship* (**under peer review**), <https://innovation-entrepreneurship.springeropen.com/>
- VII. Jjagwe, R., Kirabira, J. B., & Mukasa, N. A framework for commercialization of technological innovations in Uganda: an integrated firm-specific, market-centric, and policy-related model. *Journal of African Business* (**under peer review**), <https://www.tandfonline.com/journals/wjab20>

## CONTRIBUTIONS OF THESE PAPERS TO SCIENCE

### **Paper I**

The paper reports results emphasizing that the NIS directly affects interaction and learning among actors in an innovation ecosystem. The NIS is a key component of Uganda's R&I landscape, bringing together various actors and institutions involved in the country's transformation. This study explored the relationships among NIS actors, offering insights into the utilization of Uganda's unique institutional and economic landscape for sustainable growth. It identifies key drivers, such as improved collaboration between the government, industry, and academia, and strategic policy measures in technology transfer and innovation funding, which are essential for revitalizing Uganda's innovation ecosystem. Systematic document reviews based on the SPAR-4-SLR protocol and case study techniques were employed to discuss the factors, actors, and associated linkages in Uganda's NIS ecosystem.

### **Paper II**

The paper reports results indicating that conducting R&D and protecting Intellectual Property (IP) is vital to firms' innovation and commercialization initiatives. It provides a comprehensive understanding of the innovation and commercialization characteristics of techno-business firms in Uganda, focusing on firm processes, strategies, and challenges. The study underscores the importance of grants and subsidies as the primary financing mechanism for firm activities. The study highlights that product or innovation development depends on collaborative agreements, adjustments to current products, and internal idea generation. Qualitative and quantitative research methods, including interviews and observational approaches, were employed to discuss the role of techno-business firms in shaping the country's innovation and commercialization landscape.

### **Paper III**

The paper highlights the need for GOU to prioritize institutional development, address structural problems to innovation input, promote talent flow, and rationally build regional knowledge value chains to improve innovation and commercialization efficiency. This study emphasizes the need to maintain momentum in gathering STI indicators to support the evidence-based formulation of effective STI policies. A qualitative research method using case study and interview approaches was employed to examine the contribution of R&D funding and investment to innovation commercialization.

#### **Paper IV**

The paper highlights the need for an interactive R&I ecosystem and the availability of support mechanisms at both institutional and national levels. The findings highlight the urgent barriers to be addressed, including fragmented R&I ecosystems, inadequate support infrastructure, such as technology transfer offices, and significant gaps in innovation financing. These issues underscore the urgent need for targeted policy interventions. This study provides policymakers with a data-driven foundation to craft targeted interventions to remove the identified barriers, thereby catalyzing the commercialization of innovations in Uganda's R&I institutions. A mixed-methods approach was employed to examine the factors influencing innovation commercialization at R&I institutions in Uganda.

#### **Paper V**

The paper indicates that a robust R&D infrastructure and supportive government regulations are crucial factors, and market-related elements, such as public awareness and the adoption rate of new technologies, substantially influence their effects. Bridging CVD hinges on sustainable financial systems, effective partnerships or collaborations, strong global linkages, and the availability of R&D infrastructure. This study contributes to the theoretical knowledge base by elucidating the complex factors influencing CVD in developing countries and providing practical recommendations for policymakers. It proposes a multifaceted approach to enhance innovation ecosystems, including targeted support for R&D infrastructure, facilitating market access initiatives, and modifying regulatory frameworks. A rigorous quantitative methodology encompassing comprehensive interviews and observational studies was used to evaluate the factors influencing CVD in Uganda.

#### **Paper VI**

The paper indicates that market dynamics, a robust R&D infrastructure, and supportive government regulations are among the crucial determinants of CVD, offering new perspectives on bridging CVD in Uganda. Techno-business startups must navigate market dynamics, leverage R&D infrastructure, demonstrate technological expertise, raise product awareness, and comply with government regulations. By highlighting these determinants, this study provides valuable theoretical and policy insights that can guide the development of targeted interventions to foster entrepreneurship and innovation commercialization in Uganda. A mixed-methods approach

utilizing a combination of interviews and systematic observations was employed to gain deep insights into the multifaceted determinants of CVD, aligning to understand both the qualitative and quantitative aspects of commercialization challenges in Uganda.

### **Paper VII**

The paper shows the various key factors influencing innovation commercialization, including firm-specific competencies and investment profiles, market-centric product awareness and market dynamics, and policy-related factors such as the policy environment and support schemes. It introduces a comprehensive framework that integrates strategies and measures for innovation commercialization at the firm, market, and policy levels. The study emphasizes the significance of support mechanisms and recommends micro and macro reforms to create a vibrant market for technological innovation. Multiple-case and cross-sectional survey designs were employed to identify the factors, strategies, and measures influencing innovation commercialization in Uganda.

## CHAPTER ONE: INTRODUCTION

### 1.1 Background

The advancement of Science, Technology, and Innovation (STI) is crucial for industrialization and development (Aktar et al., 2021; OECD, 2021; Hussen & Çokgezen, 2022). It enables the transformation of conceptual ideas into concrete solutions, enhances operational efficiency, and improves the accessibility of data and expertise, thereby increasing economic productivity and global competitiveness (Schwab & Zahidi, 2020; Moon, 2022; Kurpayanidi, 2023). Innovations in STI have the potential to establish new enterprises and industries that drive the commercialization of novel products and processes. Consequently, this development influences government policies aimed at value addition in goods and services, agricultural processing, technological product development, and market expansion (Mallinson, 2021; Zhang et al., 2023; Yim et al., 2024). Global trends emphasize the need for enterprises to commercialize their innovations to remain competitive and achieve sustainable growth in the global market (Min et al., 2020; Shcherbachenko & Kotenko, 2022; Butnik-Siverskyi et al., 2024). The increasing pace of innovation and commercialization has elevated the success rate of innovators and intensified market competition.

Effective commercialization enables organizations to enter new markets, strengthen industry leadership, and ensure long-term sustainability. Previous research links successful commercialization to a firm's internal capabilities, human resource strategies, top management effectiveness, and external business environment (Daneshjoovash et al., 2021; Pellikka et al., 2021; Lages et al., 2023). Despite the recognized importance of commercialization, there is no consensus among management scholars and practitioners regarding its influence on market failure (Bakhtiar et al., 2020; Kruachottikul et al., 2023a). Commercialization processes are complex, requiring a combination of entrepreneurial activities from idea generation to product launch. However, only a small fraction of innovative ideas reach commercial success, with statistics indicating that only 39% of technopreneurs believe their enterprises effectively commercialize new products or services. Moreover, one-third of senior leaders consider commercialization to be the most significant challenge (Kusumawati et al., 2022; Maulana et al., 2022; Kruachottikul et al., 2023).

The Government of Uganda (GOU) has prioritized innovation commercialization as a strategic tool for national growth, prosperity, and sustainable development. This commitment is outlined in the country's STI Policy (MFPED, 2009), National Strategic Development Framework (MFPED, 2012), and Vision 2040 (NPA, 2007). To achieve this, effective policy and strategic frameworks must be developed and implemented in the context of innovation systems (Gao, 2022; Noeh et al., 2023; Wen, 2023). Recognizing the importance of innovation and commercialization is crucial for Uganda's transformation; however, the effectiveness of policy initiatives depends on their integration into the broader innovation ecosystem (Jia et al., 2020; Stornelli et al., 2021; Al-Jayyousi et al., 2023). Uganda has made efforts to develop a framework for innovation and commercialization, and recent initiatives have demonstrated the need to improve Science and Technology (S&T) capacity that could influence and boost local innovation (Bowman, 2019). Nevertheless, a coordinated mechanism for STI policy implementation remains a challenge (Guimón, 2013). Broader issues related to Intellectual Property (IP) commercialization and the associated legal and institutional frameworks for innovation and commercialization have been identified (Nahikiriza, 2023). Additionally, increased investment in Research and Development (R&D) and implementing policy measures to stimulate the commercialization of R&D are prerequisites (Hogan et al., 2022).

Countries increasingly recognize the significance of innovation in driving economic growth and creating value. Consequently, many governments are revamping their innovation systems to remain competitive in the global market. In 2009, the Ugandan government introduced a comprehensive STI policy to provide institutional and infrastructural support for producing STI-related goods and services (MFPED, 2009). This development, together with other government efforts, university undertakings, industry contributions, and the participation of development partners, provided a solid foundation for developing more extensive and inclusive innovation policies and strategies in the country (Kapuriri et al., 2020). Uganda can gain valuable insights from other experienced countries and their legal frameworks to enhance its innovation and commercialization efforts (Min et al., 2020; Butnik-Siverskyi et al., 2024). This would require strengthening R&D investments for Uganda's growth and development.

The Ugandan policy framework for innovation and commercialization is intricate and encompasses diverse sectors and stakeholders. The GOU has recognized the importance of STI in

addressing its development challenges and promoting economic growth (Guimón, 2013). Furthermore, the development of innovation and commercialization ecosystems in the country is contingent upon government support for STI, which includes establishing an STI funding facility, promoting private sector commercialization of innovations, and enhancing institutional governance systems (Onapa et al., 2018; Nahikiriza, 2023). The formation of the innovation and commercialization framework is affected by several sector policies and legislative acts rooted in constitutional provisions that mandate the state to promote STI. It is essential to develop clear implementation plans to support these policies and possess the capacity for effective execution.

There are challenges in coordinating the STI policy framework among stakeholders. Despite the government's demonstrated political will for STI development, a more effective mechanism for policy coordination, vigorous technology development, and innovation commercialization at the knowledge generation centres is necessary (Nahikiriza, 2023). Moreover, the broader context of innovation and commercialization policy frameworks highlights the need for collaboration among the government, industry, and academia (Noya & Taneo, 2023). Uganda has developed its innovation and commercialization policy framework with significant government investment and initiatives to bolster its STI capacity. However, gaps remain in effectively coordinating the country's STI policy profile and enhancing commercialization.

Funding for innovation and commercialization in Uganda is mainly provided by international or foreign agencies, the government, and not the private sector. Unlike middle- and high-income countries, where private investment is the primary source of innovation and commercialization, Uganda's private sector is not yet capable of making significant investments in R&D (Sithole, 2020). Furthermore, the absence of venture capital support for commercializing research outcomes indicates that the Ugandan government assumes responsibility for funding research and innovation. Addressing the issue of funding innovation and commercialization in Uganda necessitates a comprehensive approach involving the collaboration of diverse stakeholders and financial instruments. The government has demonstrated strong dedication to advancing STI through initiatives such as R&D grant funding and fostering cooperation between industry and research institutions (Guimón, 2013). Despite these efforts, Uganda's innovation system is still nascent and characterized by limited technological development and commercialization.

The development of Uganda's support infrastructure has been instrumental in the advancement of innovation and commercialization. While such arrangements are in place, they are generally considered beneficial for Uganda's economic growth, provided they adhere to international standards and yield positive developmental outcomes (Ogwang & Vanclay, 2021). This support infrastructure indirectly promotes innovation commercialization by improving accessibility and connectivity (Yin & Chang, 2021; Moon, 2022). Uganda's efforts to encourage innovation and commercialization are supported by various measures, such as political initiatives, international partnerships, infrastructural advancements (Nahikiriza, 2023), and cutting-edge financial technologies such as crowdfunding (Ogwang & Vanclay, 2021). Despite facing challenges such as the need for more vigorous technology development and commercialization, Uganda is steadily creating a favourable environment for innovation commercialization. To ensure continuous progress, it is imperative to develop policies that promote innovation, facilitate collaboration between the public and private sectors, and implement innovative funding mechanisms, while adhering to global standards and establishing best practices.

The commercialization of technological innovations presents numerous challenges, including high uncertainty, extended timelines, and significant capital requirements, which can be particularly difficult for developing countries such as Uganda (Bowman, 2019; Ogwang & Vanclay, 2021). A strategic framework for innovation commercialization in such contexts should incorporate mechanisms that address these challenges. This includes fostering resilient incubator business models, enhancing collaboration among universities, industries, and government agencies, and creating innovative business models to support new ventures in established industries (Kwesiga, 2019; Ogwang & Vanclay, 2021). A comprehensive understanding of technology financing, innovation management, and institutional roles in the commercialization process is essential for supporting Uganda's innovation system (Staniulyte, 2023; Yan et al., 2024). The commercialization of innovations is further complicated by market volatility and technological interdependencies, highlighting the need for a strategic and nuanced approach to commercialization decisions (Min et al., 2020; Butnik-Siverskyi et al., 2024). Government-led initiatives such as technology parks and business incubators could play a pivotal role in fostering innovation and commercialization within Uganda (Kwesiga, 2019).

This study emphasizes the need for improvements at both the micro (technology-driven business enterprises) and macro (policies, regulations, and infrastructure) levels. It proposes a model framework to facilitate the efficient commercialization of technological innovations, thereby maximizing the potential of the STI value chain. This approach aims to enhance returns on investment and inform decision-making among firms, government agencies, and partner institutions concerning investments in Research and Innovation (R&I) to drive socioeconomic transformation. Successful innovation commercialization in Uganda requires a combination of strategic collaborations, dynamic business models, robust institutional frameworks, and tailored financing strategies (Kwesiga, 2019; Ogwang & Vanclay, 2021; Yan et al., 2024). These elements must be adapted to fit Uganda's innovation ecosystem, ensuring a seamless transition of technological innovation from conception to the market. A viable commercialization framework for Uganda should be multifaceted, incorporating technological entrepreneurship, adaptive business models, and academic-industry linkages. In addition, the development of a supportive ecosystem including educational initiatives, financial incentives, and infrastructural support is crucial. A well-structured commercialization framework plays a transformative role in translating technological innovations into market-ready products, thereby fostering economic development and national progress (Kwesiga, 2019; Ogwang & Vanclay, 2021; Yan et al., 2024).

## **1.2 Statement of the Problem**

The commercialization of innovation is vital for transforming research outputs into competitive products and services; however, the existing literature lacks a comprehensive and context-specific framework to guide this transition. While various studies have examined the components of innovation systems, none have provided an integrated, practical model that combines firm-level capabilities, market dynamics, and national policy mechanisms. Consequently, firms, researchers, and policymakers continue to operate without clear strategies for strengthening commercialization pathways. In Uganda, these gaps are deepened by fragmented and insufficient data on national innovation and commercialization systems, leading to weak strategic planning and inefficient allocation of Science, Technology, and Innovation (STI) resources. Coordination challenges among universities, firms, research centres, and government agencies further slow knowledge transfer and hinder the progression from prototypes to commercially viable products. Low national investment in R&D, approximately 0.4% of GDP compared to the international benchmark of 2–

3%, has contributed to persistent weaknesses such as inadequate market readiness, limited intellectual property utilization, and the recurring “commercialization valley of death” (CVD).

Therefore, the lack of a holistic commercialization framework represents a critical research and policy gap. There is a dire need for an integrative model that addresses both micro-level factors (including firm competencies and product-market alignment) and macro-level enablers (such as policy coherence, institutional linkages, and STI financing). Developing such a framework will support stronger commercialization performance, enhance returns on STI investments, and advance Uganda’s transition toward an innovation-driven economy.

### **1.3 Objectives of the Study**

The main objective was to elucidate a framework for the commercialization of technological innovations in Uganda.

#### **1.3.1 Specific Objectives**

- (i) To determine the linkages and interrelationships among the actors in Uganda’s national innovation system.
- (ii) To assess the contribution of R&D funding and investment to the commercialization of technological innovations.
- (iii) To examine the drivers and barriers that affect the commercialization of technological innovations.
- (iv) To develop a model framework that integrates strategies and measures for the commercialization of technological innovations at the firm, market, and policy levels.

#### **1.4 Research Questions**

- (i) What are the prevailing linkages and interrelationships among Uganda’s national innovation system actors?
- (ii) What is the contribution of R&D funding and investment to the commercialization of technological innovations?
- (iii) What are the drivers and barriers to the commercialization of technological innovations?
- (iv) How do the drivers of technological innovation commercialization interact at the firm, market, and policy levels?

## **1.5 Justification of the Study**

Technological innovation plays a crucial role in driving economic growth, industrialization, and national development. However, in Uganda, the commercialization of innovations remains a significant challenge due to inadequate institutional frameworks, limited financial support, weak collaboration among stakeholders, and fragmented innovation ecosystems. Despite efforts by the government and private sector to enhance innovation, the country continues to lag behind in transforming research outputs into viable commercial products and services. Uganda's low GII ranking and minimal R&D investment further highlight the urgent need for an effective commercialization strategy. Existing literature and policy frameworks lack a comprehensive model that integrates firm-, market-, and policy-level strategies for innovation commercialization. Without such a structured approach, innovators, technopreneurs, and policymakers struggle to bridge the CVD, and promising innovations fail to reach the market. Therefore, this study is justified in its aim to develop a model commercialization framework tailored to Uganda's unique innovation ecosystem. By addressing existing gaps, the study provides a strategic roadmap to facilitate the commercialization of technological innovations, enhance economic productivity, and strengthen Uganda's position in the global innovation landscape.

## **1.6 Significance of the Study**

This study is aligned with NDP IV (2025/26-2029/30), Vision 2040, STI Strategy for Africa (STISA) 2034, African Union (AU) Agenda 2063, and SDG 9 on industry, innovation, and infrastructure. This research has significant implications for various stakeholders, including policymakers, innovators, research institutions, businesses, and investors.

*For policymakers and STI governance institutions:* It guides the design of more coherent policies, enhances coordination across innovation actors, and supports a more efficient allocation of limited R&D resources. In this regard, the framework provides a structured basis for improving the NIS and strengthening Uganda's overall STI agenda.

*For innovators and technopreneurs:* It helps innovators to understand the commercialization process, access the necessary resources, and navigate the challenges associated with bringing new technologies to the market. It also provides practical strategies for securing investments and scaling innovations.

*For research and academic institutions:* It supports research and academic institutions in aligning their research priorities with market needs, promoting university-industry linkages, and enhancing the commercialization of research outputs.

*For businesses and investors:* By identifying investment opportunities and highlighting market potential, the study encourages private sector participation in funding and supporting technological innovation. Businesses also benefit from improved access to locally developed innovative solutions that can drive competitiveness and industrial growth.

*For Uganda's socioeconomic development:* The successful commercialization of innovations leads to job creation, industrial diversification, improved productivity, and overall economic transformation. The study aligns with Uganda's Vision 2040 and other national development strategies aimed at fostering a knowledge-based economy.

## **1.7 Research Scope**

The study focuses on developing a model commercialization framework for technological innovations within Uganda's innovation ecosystem. The scope of this study covers the following aspects.

*Key actors in innovation commercialization:* The research examined the roles of government agencies, research institutions, academia, private sector entities, and financial institutions in facilitating the commercialization process.

*Commercialization challenges and opportunities:* The study assessed barriers such as financial constraints, weak policy frameworks, limited market access, and intellectual property issues while identifying opportunities for strengthening innovation ecosystems.

*Comparative analysis:* The research benchmarks best practices from other countries with successful innovation commercialization models to extract lessons applicable to Uganda's context.

*Framework development:* The study designs a comprehensive commercialization framework that integrates firm-level, market-driven, and policy-oriented strategies to enhance the success rate of technological innovations.

*Geographical coverage:* The research primarily is focussed on the Ugandan context but draws insights from regional and international innovation ecosystems to enhance the applicability of the framework.

*Timeframe:* This study examined recent trends, policies, and innovation commercialization efforts over the past one and a half decades to ensure the relevance of the findings and their implications to the Ugandan context.

## **1.8 Conceptual Framework**

Figure 1.1 delineates Uganda's NIS and underscores the significance of harmonizing policy/regulatory, market/economic, and technical/technological components to efficiently introduce technological innovations into the market (OECD, 1999; Noeh et al., 2023). The framework highlights the interactions between NIS actors and factors (independent constructs) that affect national innovation and commercialization capacity (dependent construct), thereby impacting the country's growth, job creation, and competitiveness. This study modified and consolidated the OECD NIS framework conditions under policy/regulatory, market/economic, and technical/technological factors in accordance with Uganda's innovation ecosystem. Modifying the OECD NIS framework strengthened the analysis by offering established constructs to interpret the study results. The study mapped the policy/regulatory, market/economic, and technical/technological factors (framework conditions), NIS actors and enablers that facilitate innovation commercialization in a low developed resource setting like Uganda. Under conducive framework conditions, NIS enablers (enabling policy environment, R&I funding, institutional frameworks) facilitate NIS actors (research and academic institutions, techno-business firms, incubators, accelerators, innovation hubs, government MDAs) to achieve their full potential. In developing a commercialization framework for technological innovations in a low-developed setting and in line with the conceptual framework, the following independent, intermediate, and dependent constructs were considered.

### ***1.8.1 Independent Constructs***

#### *Firms' Capabilities and Networks*

The efficacy of technological innovation depends on its technical proficiency and business acumen. Research has demonstrated that even with superior technology, a product may not exhibit

performance superiority over less advanced alternatives that are strategically marketed and managed. This study examined the technical and entrepreneurial knowledge and abilities that are crucial for successful innovation commercialization by researchers, innovators, and technopreneurs. Firms must acquire entrepreneurial knowledge and skills beyond scientific and technical expertise (Abate & Sheferaw, 2023; Asad et al., 2023; Sendawula et al., 2023) to support innovation commercialization.

### *Supporting Institutions*

Infrastructure support is crucial for techno-business firms striving to become successful ventures. Establishing incubation facilities for startups, accelerator programs, private and public research institutes, and facility parks can aid enterprises in various ways (Kwesiga, 2019; Kolade et al., 2021; Ogwang & Vanclay, 2021). Geographical proximity to supportive institutions facilitates the establishment of formal and informal connections and networks among relevant parties. This proximity enables unimpeded exchange of information and concepts among stakeholders. These connections further facilitate specialization, technological advancement, adaptability, creativity, and competitiveness (Asad et al., 2023). This study evaluated the role of support/incubation facilities in facilitating innovation commercialization.

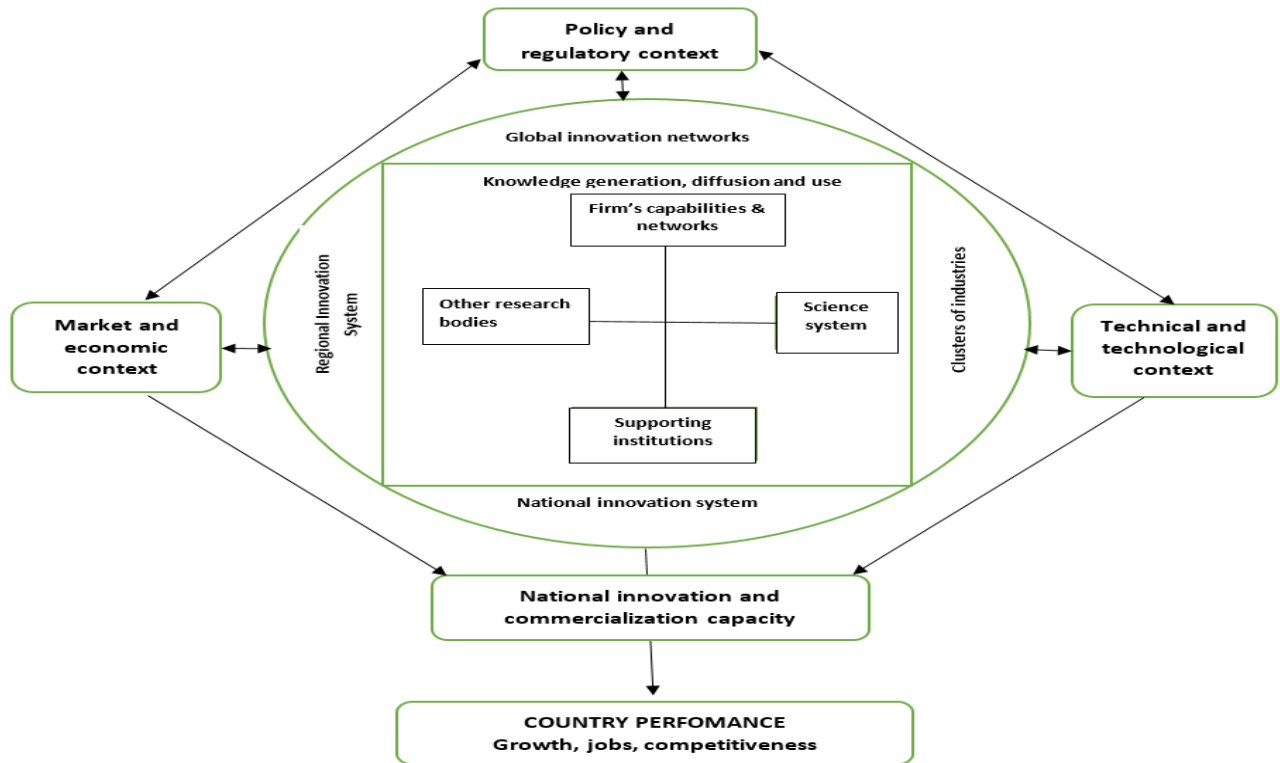
### *Science System Financing Mechanism*

Owing to resource limitations, many firms are compelled to seek additional funding to transform their inventions into groundbreaking innovations. Sustainable financial mechanisms must be created to cater to the financial requirements of techno-business firms that have completed the R&D phase and are planning to launch innovations in the market (Hanlin et al., 2020; UNCTAD, 2020). Collaboration with other institutions for joint research initiatives is the most effective strategy for fulfilling R&D funding requirements (Hanlin et al., 2020; UNCTAD, 2020). This study examined the role of collaborative research and the various financing mechanisms available to technology-driven enterprises for innovation commercialization.

### *Market-Oriented Technology Development*

Achieving success in the technology commercialization industry requires the development of a value proposition that distinguishes a product or service from its competitors and demonstrates its value to customers. Although technology can solve existing challenges and contribute to

environmental sustainability, its commercial viability is crucial. Without this, the likelihood of failure increases, and investors are less likely to invest in projects that do not offer a reasonable Return on Investment (ROI) (Ojubanire et al., 2023; Shahidan et al., 2023). This study assessed the competitive landscape of technological innovation among techno-business firms by evaluating the potential threats from new market entrants, substitute products, and the bargaining power of customers and suppliers.



**Figure 1.1:** Conceptual framework modified according to OECD (1999)

### *Innovation Commercialization Strategies*

The adoption of a comprehensive commercialization approach by techno-business enterprises is crucial (Butnik-Siverskyi et al., 2024; Min et al., 2020; Shcherbachenko & Kotenko, 2022). The strategy should encompass technological aspects and the management of the entire product commercialization process. Several options for innovation commercialization are available, including contractual agreements, licensing, assignments, joint ventures, and spin-off companies. In Uganda, the National Intellectual Property Policy (MoJCA, 2019) provides the URSB with the responsibility of commercializing innovations. This study discusses the various drivers and

barriers influencing innovation commercialization among researchers, innovators, and technopreneurs.

### ***1.8.2 Intermediate Constructs***

The intermediate variables included the following: market entry and competence (Kreiterling, 2023); protection, development, and deployment of commercialization strategies (Datta et al., 2014); market size and potential (Avenyo et al., 2021); organizational interaction and learning (Gidron et al., 2021); and technological innovation capabilities within the ecosystem (Kusumawati et al., 2022).

### ***1.8.3 Dependent Constructs***

According to the conceptual framework, the dependent variable is commercialization success or probability (Shcherbachenko & Kotenko, 2022). The NIS consists of STI actors' connections, interactions, and knowledge base, which, when applied comprehensively, enable innovators across the NIS to hone their skills, foster wealth creation, and promote prosperity (Noeh et al., 2023; Wen, 2023). When conditions are conducive, NIS actors, factors and constraints interact resulting in learning and knowledge exchange, and improving ecosystem creativity, innovation and commercialization outcomes, thereby impacting the country's growth, job creation and competitiveness (Mulumba et al., 2018).

When viewed in its entirety, the NIS can serve as a productive mechanism that facilitates the generation, development, and application of novel ideas and innovations to improve outcomes, processes, and services (Staniulyte, 2023; Yan et al. 2024). Comprehending the intricate connections between institutional stakeholders engaged in innovation initiatives or procedures is vital for boosting a country's technical and economic performance (Chen & Ou, 2021; Fernandes et al., 2022). The framework strengthened the analysis by offering established constructs to interpret the study results.

## **1.9 Thesis Structure**

This thesis comprises six chapters. Chapter one elucidates the need to develop a comprehensive framework that integrates strategies and measures for innovation commercialization at the firm, market, and policy levels. Chapter two explores the relevant literature, highlighting the key

empirical concepts underpinning the study. Chapter three highlights the tools, techniques, and methods employed to achieve the study objectives. Chapter four presents the results in line with the study objectives and research questions. Chapter five discusses the results and highlights the theoretical and policy implications of the study, together with the scientific contribution and originality of the thesis. Chapter six discusses the conclusions, proposed recommendations, study limitations, and ideas for future research.

## CHAPTER TWO: LITERATURE REVIEW

### 2.1 Introduction

This chapter reviews the existing literature on innovation commercialization, national innovation systems, firm-level innovation capabilities, and policy dynamics influencing technology diffusion. The review synthesizes global and regional evidence to highlight what is known, what remains unresolved, and how these gaps justify the development of an integrative commercialization framework for Uganda. The chapter concludes with a clear articulation of the conceptual research gap guiding this study.

### 2.2 Concept of Innovation Commercialization

Innovation commercialization refers to the processes through which research outputs, prototypes, and emerging technologies are transformed into market-ready products and services. Scholars identify commercialization as the bridge between invention and economic value creation (Gbadegeshin, 2018; Butnik-Siverskyi et al., 2024), encompassing activities such as technology validation, market assessment, product development, intellectual property (IP) management, and scaling strategies.

Commercialization is often conceptualized as a non-linear, iterative process influenced by multiple actors and system-level conditions (Gong et al., 2021; Kusumawati et al., 2022). The literature distinguishes between early-stage commercialization (proof of concept, prototyping, and technology readiness) and late-stage commercialization (market entry, scale-up, and diffusion). Globally, successful commercialization correlates with strong innovation capabilities, robust IP systems, supportive financial ecosystems, and well-coordinated institutional linkages.

Despite substantial scholarship on innovation systems, the literature reveals that commercialization, as a distinct research domain, remains under-theorized, especially in developing countries (Shcherbachenko & Kotenko, 2022; Lages et al., 2023). Most frameworks are designed for advanced economies and have limited applicability to African contexts, which are characterized by resource constraints, fragmented ecosystems, and weak policy coherence.

## **2.3 Theoretical Foundations for Innovation Commercialization**

### ***2.3.1 National Innovation Systems (NIS) Theory***

The NIS theory posits that innovation performance depends on interactions among firms, universities, research institutes, financial systems, and the government. A strong NIS ensures knowledge flow, learning mechanisms, and institutional coordination necessary for commercialization. However, literature shows that in many developing economies, NIS structures are weak, fragmented, or poorly aligned with industrial needs, thereby impeding technology uptake (Gao, 2022; Wen, 2023). Scholars have argued that innovation systems are deeply rooted in evolutionary economics, a field fundamentally tied to Schumpeter's groundbreaking work on innovation and economic growth in the 20th century (Schumpeter, 2017). Compared to neoclassical and traditional economics, evolutionary economics posits that economic agents exhibit bounded rationality rather than being rational. Alternatively, these agents enhance their comprehension of the world through empirical investigation and learning from errors (Zhang & Hartley, 2018). Consequently, they form nonlinear, dynamic relationships and connections that benefit from knowledge accumulation in various ways, which is the defining characteristic of innovation systems (Pellikka et al., 2021; L. Wang et al., 2024; Yim et al., 2024).

The concept of innovation systems has garnered considerable attention from scholars and policymakers, as evidenced in Chaminade et al. (2018) and Makkonen (2019). Often used as a rhetorical device, it is a critical and analytical framework for comprehending technological change and national development. By adopting an innovation systems approach, researchers and policymakers can analyze innovative activities more comprehensively, considering the outcomes (innovation), the processes that lead to those outcomes, and the diverse stakeholders involved in generating them. This strategy encompasses university and corporate R&D initiatives, government policies, educational methods, and motivational frameworks. The innovation systems approach posits that innovation processes are complex and involve interdisciplinary teams collaborating in co-evolutionary development. This perspective contrasts with the linear innovation model, which conceptualizes innovation as a sequential progression from fundamental research to applied studies, product creation, and technology dissemination.

While the linear model gained prominence in the 1950s and the 1960s and continued to influence some countries' science policies, the innovation system approach recognizes innovation as a

multifaceted, recursive process. Noeh et al. (2023) contend that the linear model's persistence is attributable to its simplicity and supporting statistical evidence. Since the 1960s, data has been collected and categorized into three primary domains: fundamental research, applied R&D, and technology dissemination. Policymakers and science advocates frequently use these categories to support and justify funding. In the 1970s, the linear model, which asserts that market needs are the primary drivers of research, development, and technological innovation, gained widespread acceptance (Planko et al., 2017; Noeh et al., 2023). This led to the development of "technology push" and "market pull" models. Critics of the linear model argue that it is insufficient because it fails to provide the necessary feedback mechanisms for the innovation process. Furthermore, in the contemporary highly competitive global market, where product lifecycles are progressively shortening, it is imperative to seamlessly integrate R&D activities into a comprehensive innovation process (Bryson et al., 2020).

Critics maintain that the insufficient execution of research outputs can be attributed to limitations associated with the linear model. These inadequacies are often referred to as "valleys of death" (Ellwood et al., 2022). Consequently, innovation systems have gained broader recognition and acceptance, emphasizing the iterative and collaborative nature of innovation as a process involving various stakeholders in a perpetual learning environment. This perspective acknowledges the intricate relationships between organizations and institutions, with institutions conceptualized as the "rules of the game." These rules encompass policies, laws, behaviours, norms, routines, and practices that influence interactions among individuals and groups (Bryson et al., 2020; Sadyrova et al., 2021). Recently, our understanding of innovation systems has evolved and expanded. Researchers are divided on whether they should consider a theoretical or conceptual framework. Although Noeh et al. (2023) warned of potential conflicts arising from various interpretations and applications, they acknowledged that innovation systems fundamentally involve interaction and learning among ecosystem actors.

According to Chaminade et al. (2018), a more comprehensive conceptualization of innovation systems considers them to be open, dynamic, and complex entities. These systems encompass interactions within and between organizations, institutions, and socioeconomic structures. Such relationships play a central role in determining the rate and trajectory of innovation and in developing competencies grounded in scientific and experiential learning processes. Although the

Although the NIS framework effectively maps actors and institutions, it provides less guidance on the micro-level strategies that firms need to navigate this system and the mechanisms for collaboration to de-risk CVD. This study addresses this gap. This thesis examines the concept of innovation systems that recognize the potential for innovation to manifest at multiple scales, including local, regional, national, or sectoral levels, contingent upon the specific technology, product, or service under development (Chaminade et al., 2018; Noeh et al., 2023). This study employs an innovation system framework to examine innovation processes across multiple sectors. This study explored these processes in academic institutions, government-funded research organizations, businesses/firms, government agencies, and communities in which the research was conducted.

### ***2.3.2 Triple Helix and Quadruple Helix Models***

The Triple Helix model emphasizes university, industry, and government collaboration as a driver of innovation (Abbas et al., 2019; Cai & Etzkowitz, 2020) and their involvement in a knowledge-based economy. The Triple Helix model elucidates the interaction, reciprocal support, and collaborative development among universities, industries, and governmental entities, with academic institutions assuming an expanded role (Noya & Taneo, 2023; Wang et al., 2024). Extensions such as the Quadruple Helix integrate civil society and user communities. These models underscore the importance of collaborative networks, knowledge exchange, and joint problem-solving as prerequisites for successful commercialization. Evidence suggests that without strong linkages, research outputs remain locked in academic institutions and fail to reach commercial markets.

Within the Triple Helix framework, the functions of these three spheres evolve, enabling each to adopt the responsibilities of the others in specific contexts (Cai & Etzkowitz, 2020; Zhuang et al., 2021). This paradigm facilitates the integration of functions and the establishment of intermediary or connecting organizations, as collaboration between universities, industries, and the government engenders flexibility in institutional boundaries. While the Triple Helix model provides a useful structural blueprint, its application in the Ugandan context, with its nascent clusters and unique governance challenges, remains underexplored and requires empirical investigation to understand the precise nature of effective collaboration. Despite extensive research on the impact of the Triple Helix model on innovation commercialization, there remains a lack of understanding of how it

interacts with Uganda's local cultural and economic dynamics. This approach directly highlights the gaps and sets the stage for the relevance of this study.

### ***2.3.3 Resource-Based View (RBV) and Dynamic Capabilities Theory***

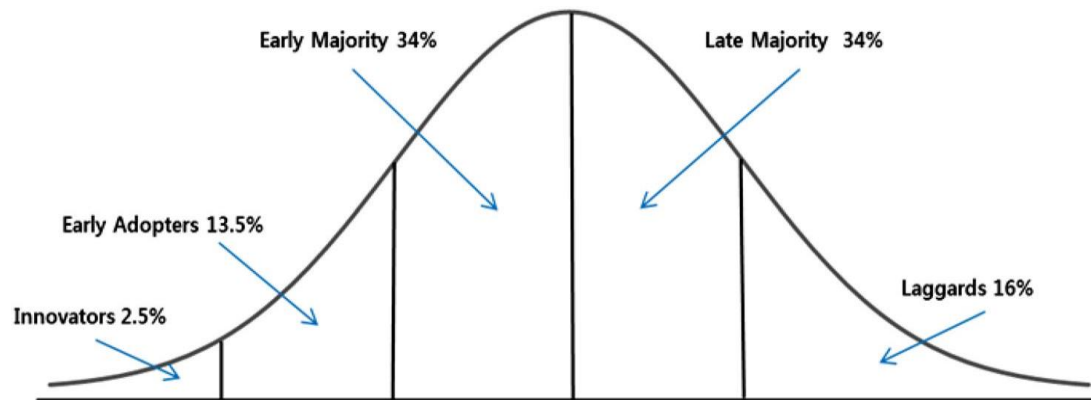
The resource-based view (RBV) highlights internal firm capabilities, technical, managerial, financial, and strategic, as key determinants of commercialization success. Dynamic capabilities theory extends this by emphasizing a firm's ability to integrate, reconfigure, and adapt resources in response to changing market conditions (Mukhtar et al., 2021). Together, these theories underscore that firm-level competencies such as technological expertise, market orientation, and strategic agility, are essential but must be complemented by supportive ecosystem factors to overcome challenges such as CVD. Studies have shown that firms with strong dynamic capabilities are more effective in evaluating technologies, identifying market opportunities, and scaling innovations (Mukhtar et al., 2021; Shcherbachenko & Kotenko, 2022).

In the Ugandan context, these frameworks guide the development of tailored strategies that address specific technological regimes, firm sizes, and socioeconomic conditions, facilitating the effective management of the entire innovation process from financing to market legitimation. The situation in Uganda necessitates a comprehensive approach to innovation commercialization that considers the country's unique technological regimes, firm size, and socioeconomic conditions (Nahikiriza, 2023; Tweheyo et al., n.d.). Strategies should be customized to effectively manage the innovation process, ranging from financing and development to diffusion and legitimation, focusing on overcoming socioeconomic barriers and optimizing techno-business incubation models to the local context. Understanding the role of system builders and the significance of aligning visions within the innovation system can further facilitate innovation commercialization in Uganda. Uganda offers numerous opportunities to improve research and innovation capabilities. Given the increasing demand for stakeholders, enhancing institutional capacity by implementing novel institutional transformation and growth models is crucial.

### ***2.3.4 Market Systems and Diffusion of Innovations***

Diffusion theory suggests that market acceptance depends on the perceived value, compatibility, complexity, trialability, and observability of innovations. Commercialization literature highlights that firms in developing economies often struggle with inadequate market intelligence, weak

customer orientation, and limited competitive positioning, which constrain their ability to achieve market readiness. The Technology Adoption Lifecycle (TAL) outlines the acceptance of new products based on the demographic and psychological traits of adopter groups. The S-curve represents products that incorporate the latest technologies and market trends (Byun et al., 2018; Mogull, 2021). The lifecycle curve is illustrated by plotting time on the horizontal axis and the cumulative number of adopters on the vertical axis (Figure 2.1).



**Figure 2.1:** Technology adoption lifecycle (Source: Byun et al., 2018)

Byun et al. (2018) noted that innovators who first embrace discontinuous innovation make up approximately 2.5% of all consumers. Early adopters account for approximately 13.5% of the total population. The early majority (pragmatists), who adopted slightly ahead of the general population, comprise approximately 34% of the population. The late majority (conservatives) account for 34% of the total population. Laggards or innovation skeptics constitute approximately 16% of the total population. This adoption cycle indicates that technological innovations do not immediately impact the market and consumers as they require time to promote the adoption of products, technologies, or ideas associated with uncertainty and risk (Byun et al., 2018; Mogull, 2021).

Although the TAL model is well established, its application varies according to context. Mogull (2021) noted the need for distinct marketing strategies throughout the lifecycle, particularly for technical products, which necessitates an understanding of consumers' psychological motivations. Chen (2024) supported this model in secondary education, highlighting the importance of early adopters and interpersonal networks in spreading new teaching methods. This implies that although the lifecycle model is broadly applicable, the factors influencing adoption can differ significantly based on a specific innovation (Mogull, 2021; Chen, 2024).

TAL provides a framework for understanding the spread of innovation within a social system and describes the market's readiness but does not provide strategies for Ugandan firms to bridge the chasm between early adopters and the early majority with limited marketing budgets. Marketing strategies, individual and organizational traits, and perceived innovation attributes influence adoption in different contexts. Although the stages of the model are consistent, the processes within each stage are complex (Mogull, 2021; Chen, 2024). TAL may oversimplify the nonlinear nature of innovation diffusion. Critics argue that it overlooks potential reverse adoption or discontinuance at any stage, and that categorizing adopters into distinct groups fails to capture the nuanced decision-making processes in today's fast-evolving technological landscape.

#### **2.4 Global Perspectives on Innovation and Commercialization Pathways**

International evidence indicates that successful commercialization requires coordinated support systems, including: a) dedicated R&D investments (2–3% of GDP in OECD countries); b) strong technology transfer offices; c) venture capital and innovation financing instruments; d) predictable regulatory and IP frameworks; e) structured incubation and acceleration programs; and d) clear commercialization roadmaps and guidelines. Countries such as South Korea, China, and Germany demonstrate that commercialization thrives where government policies align with industrial priorities (Gong et al., 2021; Lages et al., 2023), and where firms receive structured guidance on product development and market entry.

Innovation and commercialization pathways have evolved over time, involving aspects of technological advances and market demand. The first-generation model posits that all innovations stem from scientific advancements and that new industries arise mainly because of technological opportunities (Lüdeke-Freund, 2020; Bedoya Villa et al., 2023). The second-generation model emphasizes the market-driven nature of innovation based on market demand rather than technological change (Table 2.1). The third model focuses on the interplay between technological capabilities and market demand, and the convergence of these factors within an innovative enterprise. The fourth-generation model emphasizes the parallel innovation process, which connects business operations through various feedback loops (Lüdeke-Freund, 2020; Bedoya Villa et al., 2023).

The fifth-generation networking model, which is based on the chain-linked model and includes a strategic component of collaborating with company integration, expanding the relevance of

information and communication technologies, and utilizing expert systems and networks (Lüdeke-Freund, 2020; Bedoya Villa et al., 2023), has been defined as an integrated, parallel, flexible, and networked innovation process since the early 1990s. The sixth-generation model elucidates the strategic flow of knowledge, both inward and outward, to enhance internal innovation capabilities and expand the scope of external innovation utilization. This model emphasizes the significance of intentional knowledge transfer in stimulating innovation within an organization and extending its application to external market contexts (Asad et al., 2023). The open innovation paradigm posits that organizations employ external and internal ideas and pathways to enhance their technology (Table 2.1).

**Table 2.1:** Summary of the innovation generation process models

<b>Generation</b>	<b>Innovation Model</b>	<b>Period</b>	<b>Author(s)</b>	<b>Essence of the Model</b>
1	Technology push	1950s – late 1960s	Usher (1955)	Linear process
2	Market (need) pull	Late 1960s – first half of 1970s	Myers & Marquis (1969)	R&D on customer wishes
3	Coupling model	Second half of 1970s – end of 1980s	Mowery & Rosenburg (1979)	Interaction of different functions
	Interactive model		Rothwell & Zegveld (1985)	Interaction with research institutions and market
4	Integrated model	End of 1980s – early 1990s	Kline & Rosenburg (1986)	Simultaneous process with feedback loops; Chain-linked model
5	Networking model	1990s	Rothwell (1992)	System integration and networks (SIN)
6	Open innovation	2000s	Chesbrough (2003a)	Innovation collaboration and multiple exploitation paths

**Source:** Bedoya Villa et al. (2023)

Lüdeke-Freund (2020) and Bedoya Villa et al. (2023) emphasized the significance of employing cyclical and dynamic models to improve firm adaptability in a globalized economic environment.

This study highlights that innovation generation process models have shifted from rigid linear structures to more flexible, iterative, and open systems in recent years. The literature suggests that incorporating external inputs, embracing disruption, and fostering adaptability are essential for successful innovation. These models encompass control theory-based frameworks, open innovation, and cybernetic models, each of which has strategic value in managing innovation within organizations (Bedoya Villa et al., 2023).

The evolution from linear (1G/2G) to coupling (3G/4G) and finally to networked and open (5G/6G) models reflects a growing recognition of innovation as a complex, non-linear, and collaborative process. The most contemporary models (Open Innovation, 6G) align closely with the principles of the NIS and Triple Helix. However, these models are often developed from and for the context of advanced, well-resourced economies. Their applicability in settings such as Uganda, where financial resources are scarce and institutional linkages are weak, is a central question explored in this study.

## **2.5 Innovation Commercialization Challenges in Developing Countries**

Literature from sub-Saharan Africa highlights recurring challenges (Bakhtiar et al., 2020; Lages et al., 2023) such as: a) weak institutional linkages across innovation actors; b) fragmented and underfunded R&D systems; c) limited intellectual property awareness and utilization; d) inadequate financing for high-risk technologies; e) poor technology transfer mechanisms; f) low absorptive capacity among firms; and f) weak market research and product development processes. These systemic weaknesses often lead to what is termed the "commercialization valley of death" a stage between prototype development and market entry where innovations frequently fail due to financial, technical, or institutional barriers.

Innovation commercialization entails transforming unprocessed resources into final products and establishing frameworks that facilitate industrial manufacturing. Development planners have traditionally emphasized the connection between technopreneurship and industrialization. Technopreneurs are crucial for innovation commercialization, driving the shift from a traditional low-income economy to a modern one (Lüdeke-Freund, 2020). According to Loganathan and Subrahmanya (2022), technopreneurship encompasses identifying market opportunities and establishing new techno-businesses to capitalize on them. The manufacturing industry

significantly contributes to economic growth owing to technological advancements that increase productivity and drive innovation, necessitating structural changes to critical factors such as human skills, capital, institutions, and entrepreneurs (Asad et al., 2023).

According to Abate and Sheferaw (2023), outsourcing opportunities provided by large corporations, medium-sized enterprises, and innovative technology startups facilitate interconnections between small and established businesses. These relationships develop as small businesses supply intermediate inputs to firms of various scales, including newly established technology-driven ventures. Small businesses and potential technopreneurs require financial resources to maintain their operations. Operating within clusters can help small enterprises overcome growth limitations (Igwe et al., 2020; Abate & Sheferaw, 2023). Encouraging technopreneurship can aid the commercialization process, and techno-business incubation highlights national and regional strengths through clustering and networking, which can assist small businesses in expanding and contributing to commercialization. Consequently, techno-business development has been linked to commercialization (CHANE & Atwal, 2023).

Ensuring favourable technopreneurship conditions is crucial for achieving innovation commercialization. A developmental state must promote technopreneurship, which fosters commercialization (Suryati et al., 2020; Noeh et al., 2022). The government plays a vital role in shaping organizations and communities and creating the necessary conditions for commercialization. An innovation system and cluster-based development approach are proposed to provide support services for fostering knowledge-intensive enterprises. These services encompass linkages to academic institutions, research centres, venture funding sources, and global collaborative ventures. Research has demonstrated that the presence of industry clusters can influence competitiveness at both national and international levels (Gerli et al., 2022).

Uganda's recent decline in commercial production is attributed to inadequate infrastructure, a dearth of skilled industrial labour, underdeveloped technological capabilities, low investment rates, underutilization of abundant natural resources, and insufficient technological expertise (Salmon et al., 2020; Okwakol et al., 2022). In contrast, developed countries have demonstrated enhanced capabilities across multiple sectors. These include improving the macroeconomic environment, developing robust institutions, adapting to emerging technologies, constructing competitive and efficient infrastructure, effectively utilizing natural resources, optimizing

organizational structures and markets, and emphasizing skill development to address challenges and enhance competitiveness (Schwab & Zahidi, 2020; Moon, 2022). While technopreneurship highlights the key commercialization agent, it does not detail the integrated support system (finance, policy, market access) needed to carry them across the CVD.

## **2.6 Uganda's Innovation and Commercialization Context**

Studies on Uganda's STI landscape have revealed several structural limitations.

### ***2.6.1 Low R&D Investment and STI Financing Constraints***

Uganda's GERD remains approximately 0.4% of GDP, far below the international best practice. The literature associates low STI investment with limited laboratory capacity, weak R&D infrastructure, and insufficient funding for proof-of-concept and scale-up activities. According to the NPA (2020) and Okwakol et al. (2022), public research institutes and universities in Uganda primarily provide STI financing. The average GERD in Uganda between 2014/15 and 2018/19 was approximately 0.4% (NPA, 2020; Sithole, 2020; UNCTAD, 2020). This figure is significantly lower than that of the Republic of South Africa, which reported a GERD of 0.8% to 1%, and Sweden, which spends approximately 4% of its Gross Domestic Product (GDP) annually on R&D (Schwab & Zahidi, 2020; OECD, 2021). Uganda spent 0.01% of its GDP on business R&D and received approximately 250 patent applications but only two patent registrations (NPA, 2020; Sithole, 2020; UNCTAD, 2020).

Uganda's Technology Achievement Index (TAI) is projected to rise from 0.15 in the disadvantaged group to 0.21 by 2020, placing the country in the dynamic adopter category. This indicates that Uganda will achieve middle-income status or SDG 1 to eradicate extreme poverty (NPA, 2020; Dutta et al., 2022; Alqararah, 2023). The third result area is enhanced R&D intensity or increasing GERD as a proportion of GDP from 0.5 to 1 percent, as proposed by the African Union. This is a crucial milestone for STISA in 2024 (African Union Commission, 2014; Sithole, 2020). According to the STI Statistical Abstract, 2016, GERD decreased from 0.5% in 2010 to 0.23% in 2014, whereas TAI decreased from 0.15% in 2010 to 0.14% in 2014 (UNCST, 2016b; Sithole, 2020).

Governments and development partners largely fund STI programs and initiatives. For instance, in FY 2016, the Ugandan government spent an estimated 42% of the total R&D funding, while development partners contributed 51% and other sources contributed 7% (UNCST, 2016b; Sithole,

2020; UNCTAD, 2020). The government primarily covered administrative expenses such as utility bills, maintenance costs, and employee wages, while private actors made minimal contributions. Currently, Ugandan scientists rely on foreign grants and donations for their research. However, the domestic funding arrangements for STI are becoming increasingly stable and sustainable. Countries such as South Africa and Sweden have established separate public financing mechanisms for STI, including funding for scientists, researchers, and innovators, as well as a nationwide grant facility awarded on a competitive basis (Schwab & Zahidi, 2020; OECD, 2021).

Businesses typically require a significant amount of capital to develop their discoveries because of limited resources. Specific financial structures must be devised to address the financial demands of enterprises that have completed the R&D phase and seek to bring their products to market. The most well-known method for meeting R&D financial needs is collaborative research with other institutions. This approach has been recommended by various researchers, including Bryson et al. (2020) and Zhu et al. (2020). Techno-business enterprises and R&D organizations should adopt a comprehensive approach to commercialize technological advancements that extend beyond technology and encompass the administration of the entire commercialization process (Freudenreich et al., 2020; Farooq et al., 2021). Contractual arrangements, licensing, assignments, joint ventures, and spin-off companies are available to commercialize technological advancements. The Uganda Registration Services Bureau (URSB) is responsible for implementing the Uganda Intellectual Property Policy by commercializing Ugandan technologies (MOJCA, 2019; NPA, 2020).

According to Zhu et al. (2020) and Lefebvre et al. (2022), limited access to financing has a significant impact on innovation, which cannot be overstated. Therefore, it is crucial to recognize that funding R&D does not always equate to funding innovation. Although investment in R&D is an essential aspect of an innovation ecosystem, organizations and industries require financial resources to enhance their innovation capabilities and achieve greater competitiveness and commercial success at both national and global levels. Uganda's GERD paints a picture of an innovation system in distress, one with stagnant inputs, weak capacity for technological absorption and creation, and critically low returns on innovation investments as measured by commercial outputs.

### ***2.6.2 Fragmented Coordination Across Innovation Actors***

Research shows inconsistent collaboration among universities, research centres, industry actors, and government agencies. Innovation initiatives often operate in silos, resulting in duplication, inefficiency, and weak technology transfer. Effective hybrid organizations, specifically incubators, have been recognized for their capacity to facilitate collaboration among academic institutions, industrial entities, and government bodies (Noya & Taneo, 2023; Wang et al., 2024). These organizations contribute significantly to the survival and competitive success of innovative clusters which drive economic development. Innovative clusters are characterized by interconnected relationships among entities such as education, research, development, industries, and financial institutions. This creates a cycle of innovation and entrepreneurship (Cai & Etzkowitz, 2020; Zhuang et al., 2021). Clusters are geographical concentrations of interconnected yet competing businesses, suppliers, service providers, and associated institutions (Gerli et al., 2022). Clusters gained prominence in public policy discourse in the early 1990s when they were adopted by professionals across the public, private, and academic sectors (Noya & Taneo, 2023; Wang et al., 2024). Governments worldwide have embraced this concept to promote national, regional, and global competitiveness, innovation, and growth (Kurpayanidi, 2023).

In developing countries, particularly in Africa, the rate of progress has been comparatively slower than that in developed and newly industrialized countries in Asia. Consequently, analyzing and deriving insights from benchmarks can enhance collaboration and provide mutual benefits to existing Triple Helix actors. Clusters are vital for facilitating the dissemination of knowledge among businesses by bringing together neighbouring producers, suppliers, buyers, firms, and other stakeholders in the same geographical area, thereby fostering collaboration and creating mutually beneficial relationships around a specific functional niche. Cluster initiatives entail joint efforts by private industry, public authorities, and academic institutions to enhance the competitiveness of a cluster. According to Musabayana et al. (2023), small and medium-sized enterprises (SMEs) can benefit from clusters and networks by accessing skilled labour and shared business services. The physical proximity of stakeholders facilitates the development of formal and informal networks and systems. This propinquity enables an unrestricted exchange of knowledge and ideas among the participants. These connections facilitate specialization, technological advancement, adaptability, creativity, and competitiveness (Asad et al., 2023). Clustering significantly influences regional development, fostering collaboration between private and public entities for mutual

benefit through government and local investments in initiatives such as innovation hubs, research parks, and technology transfer centres (Islam & Wahab, 2021; Gerli et al., 2022).

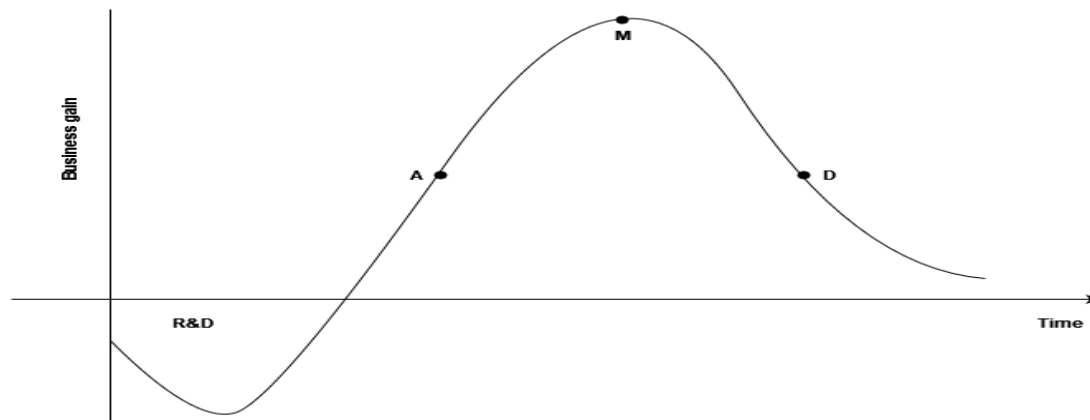
In Uganda, the concept of clustering remains nascent, with governmental bodies and educational institutions endeavouring to establish tripartite partnerships involving academia, industry, and the government in formulating policies and implementing university outreach programs (Nahikiriza, 2023). While Abbas et al. (2019) emphasized the critical role of government support in innovation commercialization, other scholars have highlighted instances in which excessive government intervention has stifled innovation (Zhu et al., 2020; Zhang et al., 2023). This discrepancy highlights the complex nature of government involvement in innovative ecosystems and underscores the need for a balanced approach.

Launching a business or commercializing research findings can be thrilling and daunting. Techno-business incubators are critical for supporting nascent enterprises and early-stage ventures, particularly in the technology sector, with substantial growth potential. Emergent businesses can derive significant benefits from the assistance provided by incubators, which provide shared workspaces, professional consultancy services, networking opportunities, and potential sources of capital that may be challenging for newly established entities to acquire independently. By providing these resources, incubators enhance firm survival and growth (Butnik-Siverskyi et al., 2024). The incubator concept is rooted in the formal and informal treatment of firm formation as an educational process. This approach is analogous to hatching chicken eggs in an artificial environment, which is the source of the term "incubator." An incubator can be conceptualized as a mechanism that facilitates the establishment of new enterprises and enhances their probability of success by providing tangible and intangible resources (Fitria & Hakim, 2022; Kruachottikul et al., 2023a). Governments worldwide recognize the importance of technopreneurship and regard techno-business incubators as essential for promoting technological innovation and guiding small and medium-sized enterprises (SMEs) to integrate into large companies' supply chains and develop sustainable economies (Asad et al., 2023; Musabayana et al., 2023).

### ***2.6.3 Limited Firm-Level Commercialization Capabilities***

Empirical studies have reported that many Ugandan firms face challenges related to technical skills, market intelligence, product testing, certification, and quality assurance. These gaps undermine competitiveness and limit the success of local innovations. As technology advances,

the relationship between Technology Lifecycle (TL) and commercial success reflects the degree of commercial achievement over time. This serves as a benchmark for optimizing R&D resource allocation and predicting the timing of R&D investment based on potential product growth and expected market profitability (Byun et al., 2018; Lüdeke-Freund, 2020). While TL emphasizes development duration and expenditure on anticipated revenues, commercial success encompasses R&D costs incurred after a product's release. TL consists of four distinct stages, as illustrated in Figure 2.2.



**Figure 2.2:** Relationship between technology lifecycle and commercial achievement (Source: Byun et al., 2018)

In the initial phase, investment risk is typically associated with technological innovation as firms conduct R&D to identify the most promising projects. This timeframe witnessed the extensive allocation of resources to R&D, aimed at assessing diverse market responses with a notably high probability of failure. The subsequent phase, signified by the attainment of development (point A), is characterized by the recuperation of invention expenditures and the prospect of rapid expansion, proliferation of innovative products, and establishment of competitive advantage by introducing the most advanced and efficient offerings. Around point M, the ensuing stage is characterized by a maturity period in which public acceptance of innovation is achieved, and competitors enter the market, resulting in supply exceeding demand and a gradual erosion of profits. After point D, the final phase is marked by a decline during which nonlinear gains transform into a zero-sum scenario because of the inability to sustain profit margins (Byun et al., 2018; Lüdeke-Freund, 2020).

#### **2.6.4 Weak Intellectual Property Systems and Technology Transfer Mechanisms**

Ugandan universities and research institutes generate significant research outputs, but commercial exploitation remains low because of limited IP management capacity, inadequate licensing models,

and weak industry engagement. Uganda boasts a comprehensive legal framework for intellectual property, encompassing the Patents Act, Copyright and Neighboring Rights Act, and Trademarks Act. These laws do not differentiate between IP ownership by individuals and organizations and allow joint ownership. Consequently, individual scientists in Uganda can claim sole ownership of IPRs unless stipulated otherwise in a contract with their employer, such as a university, or if the organization's bye-laws and policies indicate otherwise. However, many scientists and innovators in Uganda are unaware of existing IP laws, and numerous universities and research organizations, excluding Makerere University, lack effective internal policies for Intellectual Property (IP) management. Historically, Uganda has fallen behind other countries in safeguarding its IP. According to data from the Global Innovation Index (GII) (Dutta et al., 2025), Uganda filed only 39 patents since 2000, significantly fewer than Kenya's 452 patents and South Africa's 22,040 patents. Only two out of 250 patent applications were filed in the country (NPA, 2020; Sithole, 2020).

The importance of IP rights in fostering innovation and competitiveness has been recognized worldwide (Tahir et al., 2022). However, protecting IP in the digital age presents challenges for Uganda given the global nature of the Internet (Ma, 2020). Blockchain technology can be used for IP protection (Zinych, 2021) and innovative strategies employed by foreign firms in emerging economies with weak IP enforcement (Ziebermayr, 2021) can be considered for implementation in Uganda. Scholars have highlighted various aspects of IP protection including legal frameworks (Tahir et al., 2022), technological solutions (Zinych, 2021), and strategic management (Ziebermayr, 2021). These insights suggest that an integrated approach to IP protection incorporating legal, technological, and strategic elements may be effective.

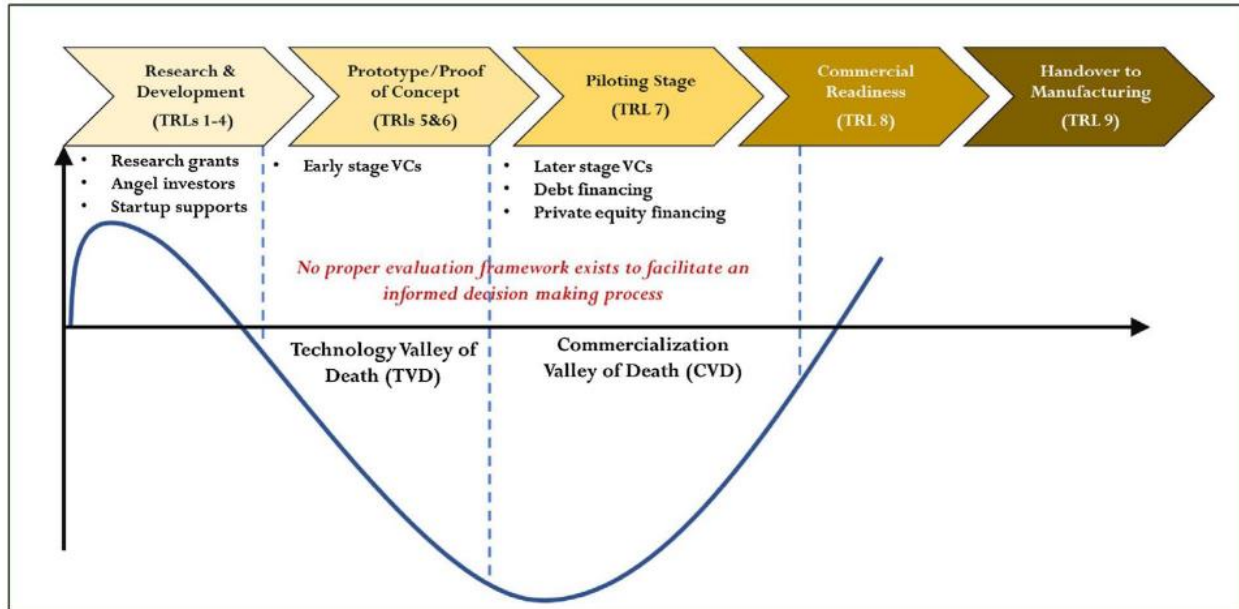
The national IP policy (MOJCA, 2019) devised by the Ministry of Justice and Constitutional Affairs and the URSB focuses on Uganda's TRIPS obligations. This policy spurs innovation, safeguards intellectual property rights, and fosters creativity, all of which are vital components of a robust IP system. Although IP protection is crucial to an effective IP regime, it is not the only one. Innovators must also consider other strategic options, such as investment and licensing, as well as the structure and functions of the innovation system to optimize the value of their IP assets (Pererva et al., 2024).

Scholars have emphasized the complexity of enforcing intellectual property rights and stressed the need for a comprehensive strategy that integrates robust legal frameworks, innovative technologies, and strategic management practices (Ma, 2020; Zinych, 2021; Tahir et al., 2022). Uganda must adapt these principles to its local context, considering the country's unique legal, economic, and technological environment, to effectively protect intellectual property rights.

### ***2.6.5 The Persistent Commercialization Valley of Death***

Local innovations frequently stall at the prototype stage because of insufficient financing, inadequate market validation, and weak institutional support. This reinforces the cycle of low innovation uptake and minimal economic impact of scientific research. The Commercialization Valley of Death (CVD) occurs early in science-based innovation when a lack of funding and support impedes a technology's continued development. This phase occurs between the invention and innovation stages or between the technical invention or market recognition of an idea (Huizingh & Biemans, 2020; Ellwood et al., 2022). It is also characterized by an inability to progress from the technology demonstration phase to the commercialization phase (Figure 2.3). Although the terminology suggests that different innovation processes are essential, this phase occurs at a critical juncture in technological development when foundational R&D is incomplete and technology commercialization is not yet fully understood. However, these two processes overlap and inform each other.

Technology transfer across CVD may pose significant management challenges (Dean et al., 2022; Son et al., 2022). It is widely accepted that the initial stages of science-based innovation are characterized by uncertainty regarding technology and market understanding, and investment decisions are rarely based on secure foundations. The inherent organizational complexity of this development phase contrasts with the two better-organized innovation functions surrounding it, namely, research and commercialization. Operations within distinct institutional frameworks accentuate the contrast between the two functions. Scientific research and commercial endeavours are governed by separate normative and cultural principles, exacerbating the disparity between their roles. Therefore, managing the transition between these logics is crucial to prevent differences from becoming a barrier to transferring technological knowledge (Al-Shaikh & Siddiqui, 2021; Takata et al., 2022). For example, discrepancies in IP-related cultural and normative logic can lead to conflicts in invention disclosure, patent licensing, and the ongoing use of IP in research.



**Figure 2.3:** Commercialization valley of death (Source: Upadhyayula et al., 2018)

Despite the growing body of research on CVD, a substantial gap remains in understanding how firm factors influence Ugandan techno-business firms' capacity to address CVD. Furthermore, the role of market-oriented elements, such as consumer preparedness and product-market alignment, has not been extensively investigated in Uganda's unique context. While the importance of technological expertise and research facilities is recognized (Everts & Drew, 2024; Sutarjo & Bajuri, 2024), there is limited understanding of how these factors interact with Uganda's distinctive market dynamics, such as consumer preferences for technological products and the digital literacy of the target audience. Therefore, this lack of comprehensive knowledge impedes the development of targeted strategies to overcome the challenges of CVD in Uganda.

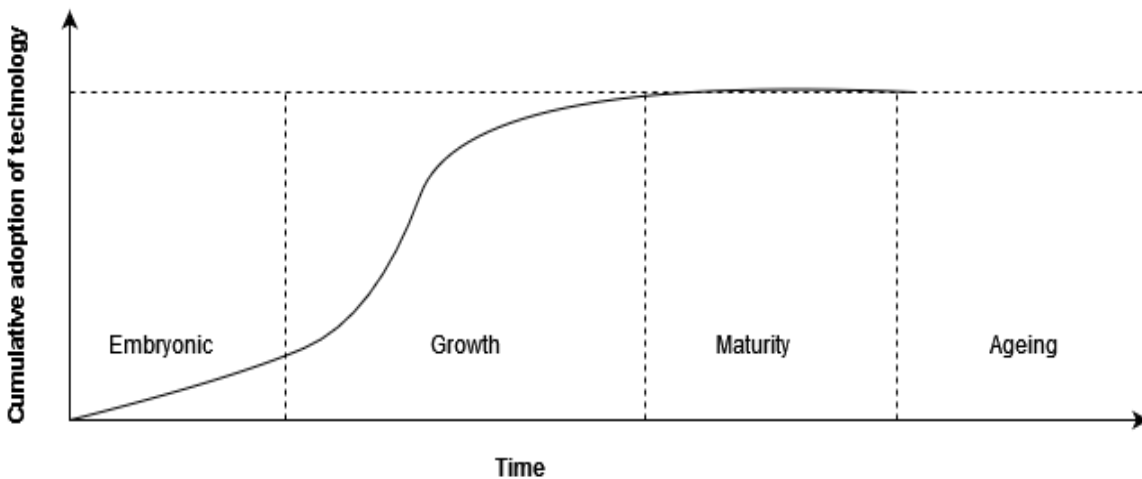
## 2.7 Existing Innovation and Commercialization Frameworks and Their Limitations

Literature reveals multiple commercialization models; stage-gate models, technology readiness levels (TRLs), innovation value chains, and NIS-based frameworks (Lüdeke-Freund, 2020; Bedoya Villa et al., 2023). However: a) they are largely developed in high-income countries; b) they focus on linear processes that do not reflect the realities of resource-constrained environments; c) they inadequately integrate policy mechanisms, firm capabilities, and market dynamics; and d) they offer limited guidance for ecosystems characterized by weak linkages and low R&D investment. No existing framework fully aligns with Uganda's contextual needs,

especially regarding coordination failures, STI financing gaps, and limited firm absorptive capacity.

Investment in R&D is widely considered the most efficacious approach to enhance the production of innovative technologies, a phenomenon referred to as the technology or supply push strategy (Scott, 2019; Mallinson, 2021). However, the demand-pull approach posits that demand for products and services plays a more significant role in driving innovative activities than advancements in knowledge. The innovation paradigm of research, development, demonstration, and deployment (RDD&D) integrates and articulates both supply-push and demand-pull approaches to technological innovation (Mallinson, 2021).

Several technology diffusion models are intended to explain the elements that impact the acceptance rate of new technologies, leading to the formulation of the technology S-curve, as shown in Figure 2.4. The diffusion of innovation theory (Mallinson, 2021; Mishrif & Khan, 2023) emphasizes the conditions contributing to consumer acceptability of innovative products, resulting in sustained product acceptability and more significant sales. Consumers' knowledge of the advantages of new products over their competitors and their motivation levels is crucial in determining their purchasing decisions (Scott, 2019; Mallinson, 2021).



**Figure 2.4:** *Technology S-curve (Source: Mallinson, 2021)*

The S-curve assumes that limited public awareness of a technology restricts its adoption rate. Conversely, the probit model suggests that diverse organizations may not adopt new technologies simultaneously because of variations in their objectives and competencies (Bedoya Villa et al.,

2023; Lüdeke-Freund, 2020). In the Probit model, diffusion occurs when various entities embrace new technologies (Fasano & Durante, 2022). Research and Development (R&D), technology lifecycle, and technology diffusion models offer a linear, sequential depiction of technological advancement. Nonetheless, contemporary perspectives challenge this notion, highlighting the importance of intricate systemic interactions between supply and demand factors (Fasano & Durante, 2022) and the role of stakeholders and entities in creating and implementing technologies within a broader socio-technical context.

According to Scott (2019) and Mallinson (2021), these models aim to elucidate innovation development, adoption, and propagation within and between organizations and society. Recent research has highlighted the absence of a unified field of study; however, a vast array of theories and methodologies has evolved to enhance our understanding of these phenomena (Lüdeke-Freund, 2020; Bedoya Villa et al., 2023; Mishrif & Khan, 2023). Despite the various models, specific recurring themes and factors have significantly impacted the innovation and diffusion processes. These include the size and configuration of the firm, market influence, profitability, and actions of firms, as well as the role of leadership, compatibility of innovation with norms and values, and attitudes towards innovation (Scott, 2019; Mallinson, 2021).

According to Mallinson (2021) and Dissanayake et al. (2022), predictors of innovation adoption can change throughout the diffusion lifecycle. Furthermore, state funding and population size may become more critical as policies spread. The frameworks and models of technological innovation and diffusion offer a conceptual understanding of how new technologies emerge and are embraced by the market and society. These frameworks elucidate the multifaceted nature of innovation processes and the myriad factors that influence the rate and extent of diffusion. While extant literature provides valuable insights, further investigation is required to refine these models and address the lacunae in our understanding of innovation adoption. The current corpus of literature establishes a robust foundation; however, considerable scope remains to enhance our comprehension of the intricate dynamics inherent in innovation diffusion, as Dissanayake et al. (2022) pointed out. Although these models explain the general dynamics of innovation diffusion, they are largely context-agnostic. They offer limited prescriptive value for policymakers and firms in Uganda, who must navigate CVD with severe constraints in funding and market infrastructure.

This indicates the need for a context-sensitive framework that adapts these general principles to local realities.

## **2.8 Synthesis and Identified Research Gaps**

The reviewed literature highlights four key research gaps.

### ***2.8.1 Absence of a Context-Specific Commercialization Framework***

No existing model holistically integrates firm-level capabilities, market conditions, and national policy mechanisms into Uganda's innovation ecosystem. Uganda offers numerous opportunities to improve its research and innovation capabilities. Given the increasing demand for stakeholders, it is crucial to enhance institutional capacity by implementing novel models of institutional transformation and growth (Pellikka et al., 2021; Lages et al., 2023). Although computer and Internet usage is currently limited, the ongoing expansion of these technologies is likely to support the growth of businesses, industries, academic institutions, and ICT innovation centers. Uganda has greater potential for skilled human resources in business, administration, and law, which are critical skills that drive improvements in the national innovation system.

The country's relatively equitable ease of doing business, particularly the objective and supportive access of enterprises to government resources, contributes to a favorable business climate for innovation. Additionally, when corporate tax rates are high, nations offer tax incentives to attract significant investment firms. Uganda's flourishing intellectual property law environment presents an opportunity for its national innovation system, although enforcement may temporarily impede the preservation of the granted rights. Accordingly, solutions to present obstacles must be proffered to promote and safeguard advancements in research and innovation. Providing financial support to pioneering prototypes through seed capital is a promising strategy. Furthermore, bolstering capacity-building measures such as skill development programs may pave the way for more rapid economic growth by employing a national innovation system framework.

### ***2.8.2 Fragmented Understanding of Uganda's Commercialization Systems***

Current studies provide sectoral or descriptive insights but lack comprehensive analyses of systemic interactions and bottlenecks. The NIS approach emphasizes the need for a comprehensive strategy encompassing various government MDAs and the private sector. Addressing the interconnected challenges within and across the STI system requires coordinated and concentrated effort. In Uganda, the NIS faces limitations due to the absence of a systematic approach to address

current STI challenges (Daneshjoovash et al., 2021; Anderson et al., 2022). To overcome these shortcomings, additional institutional strengthening measures are necessary to integrate all components of the system. Underdeveloped STI data and statistical frameworks require enhanced capacity-building efforts to facilitate the collection, storage, dissemination, and analysis of STI-related information.

Closing the existing gaps in Uganda's STI policy will require policymakers to take the following actions: increasing support for innovation in the STI sector and government MDAs; improving coherence, coordination, and alignment among the various policy areas that make up the STI policy framework; enhancing the ability to execute, analyze, and amend the STI policy throughout consecutive policy cycles; generating genuine transformational development to boost industrial output; and engaging the private sector. These interventions require a significant shift in agricultural output, from subsistence farming to commercial value chains and industrial production.

### ***2.8.3 Limited Evidence on Micro–Macro Interactions in Innovation Commercialization***

Few studies have examined how firm-level competencies interact with national innovation policies to influence commercialization outcomes. Uganda's NIS has been plagued by poor coordination, which has hindered the functioning of important institutions involved in STI. This lack of coordination has resulted in gaps in STI support and the duplication of activities. The multifaceted nature of STI in Uganda has led to the responsibility for science being shared among several line MDAs, resulting in a fragmented system that fails to provide effective coordination of STI development, associated R&D processes, and outputs. Establishing a national research agenda is expected to address these issues through coordination with the NIS.

The inability to coordinate the NIS has hindered the public's appreciation and adoption of new, emerging, and transformative technologies (Abbas et al., 2019; Kruachottikul et al., 2023). This failure impedes the achievement of institutional goals and socioeconomic transformation and development in the country. Although some of these challenges can be resolved through institutional approaches, many require systemic and multisectoral solutions.

#### ***2.8.4 Inadequate Strategies for Bridging the Commercialization Valley of Death***

There is a lack of structured pathways to guide innovators from prototype to market in Uganda's resource-constrained environment. The need for increased investment in the STI sector necessitates the implementation of novel approaches to sectoral investment financing. This includes increasing private participation in public-private partnerships (PPPs) and foreign direct investment (FDI) (Kim et al., 2019; Maulana et al., 2022). Currently, a country's investment in innovation-related research is insufficient. Uganda currently lacks a formal mechanism for funding long-term research and innovation because of shifting government priorities and the absence of an approved research and innovation framework. Research and innovation funding is a viable means of increasing research and developing innovative programmes. This impact can be enhanced by providing grantees with capacity building and technical assistance.

Uganda's R&D investment remains minimal, as evidenced by its GERD of 0.4%. This low investment level has contributed to a decline in national competitiveness in STI. This trend is at odds with the AU initiative, which has set a target GERD of 1% for all African countries. To address this issue, governments and development partners must play a significant role in promoting R&D activities. Foreign R&D funding is particularly important in Uganda. Additionally, it is crucial for the government and development partners to prioritize skill development over schooling in STEM education. Modifying the curriculum may be necessary to encourage independent thinking and creativity among learners. This is particularly important given Uganda's limited capacity to attract foreign direct investment. Uganda has faced numerous hurdles in the realm of business finance that impede growth and hamper innovation. Despite the government's provision of a broad range of financial services, SMEs' access to these services is limited because of various factors, including high interest rates, restrictive collateral requirements, and multiple processing fees. These challenges are likely to persist and continue to constrain the innovation capacity of SMEs. Additionally, the standard obstacles encountered when starting a business exacerbate these constraints.

#### **2.9 Conclusion**

The literature review shows that while innovation commercialization is widely acknowledged as essential for economic transformation, existing theoretical and empirical work does not offer a comprehensive, actionable framework tailored to Uganda's context. Accordingly, solutions to the

current obstacles must be proffered to promote and safeguard advancements in research and innovation. Providing financial support to pioneering prototypes through seed capital is a promising strategy. Furthermore, bolstering capacity-building measures such as skill development programs may pave the way for more rapid economic growth by employing the NIS framework. However, when the NIS is applied to the Ugandan ecosystem, three critical and interconnected shortcomings emerge.

- a) *The coordination gap*: This is a disconnect between the NIS structure and the micro-level actions needed by firms to cross the CVD.
- b) *The contextualization gap*: This is the lack of frameworks that adapt global models (e.g., Open innovation, TRL) to the specific financial, institutional, and market dynamics of a low-income country like Uganda.
- c) *The integration gap*: This is characterized by existing studies focusing on isolated parts of the NIS (policy, finance, firm capabilities), but no model integrates firm, market and policy level strategies into a single actionable framework.

The gaps identified justify the development of an integrative commercialization model that links firm capabilities, market readiness, and national innovation policies. The framework is designed specifically to guide Ugandan innovators and policymakers in bridging the CVD by aligning firm capabilities with targeted market strategies and enabling government policies. The next chapter presents the methodological approach adopted to design and validate this framework.

## CHAPTER THREE: METHODOLOGY

### 3.1 Introduction

This chapter presents the methodological approach adopted to develop and validate an integrative framework for innovation commercialization in Uganda. It outlines the research design, study population, sampling procedures, data collection methods, analytical techniques, validity and reliability measures, and ethical considerations. The mixed-methods approach deployed in this study is intended to ensure contextual depth, empirical rigor, and theoretical clarity in addressing the commercialization gaps identified in Chapter Two.

### 3.2 Research Design

The study adopted a sequential exploratory mixed-methods research design. This design is appropriate for complex, multi-layered research questions that require both deep qualitative insights and quantitative validation. The design consists of two phases.

#### 3.2.1 *Qualitative Exploration*

This phase explored systemic commercialization barriers, institutional interactions, and micro–macro dynamics within Uganda's innovation ecosystem. Key informant interviews (KIIs), focus group discussions (FGDs), and document reviews were used to derive preliminary constructs and thematic insights.

#### 3.2.2 *Quantitative Validation*

This phase allowed for the triangulation of qualitative findings from case studies and interviews with quantitative data from surveys. Structured questionnaires were administered to innovation-active firms, researchers, and ecosystem actors. These methods highlight the need for a more dynamic and flexible approach to understanding technological innovation adoption. This involves incorporating feedback loops and iterative processes to capture the complexity of decision-making in research, innovation, and techno-business enterprises. The integration of the two phases ensures that the resulting commercialization framework is both theoretically grounded and empirically validated.

### 3.3 Research Approach

The study used both inductive and deductive reasoning: a) Inductive reasoning guided the exploration of qualitative data to identify emerging constructs and themes relevant to innovation

commercialization; and b) Deductive reasoning guided the quantitative phase to determine the relationships between the identified themes derived from qualitative insights and existing theory. This ensured comprehensive coverage of the conceptual, empirical, and contextual dimensions of innovation commercialization in a low-resource setting.

### **3.4 Study Population**

The population for this study is composed of stakeholders across Uganda's innovation ecosystem, including: a) Innovation and R&D-intensive firms (ICT, manufacturing, agriculture); b) university researchers and technology-transfer offices (TTOs); c) government agencies responsible for STI funding and policy formulation; d) innovation hubs, incubators, and accelerators; and e) industry associations and private sector foundations. These groups were selected because they play direct roles in knowledge creation, technology development, commercialization, and policy formulation.

### **3.5 Sampling Procedure**

#### ***3.5.1 Qualitative Sampling***

Purposive sampling was used to select participants who possessed deep experience in commercialization processes based on the following inclusion criteria: a) involvement in at least one commercialization project within the last five years; b) holding a position that directly influences R&D decisions, such as project managers, principal researchers, or executives of institutions; and c) willingness to provide a detailed description of the innovation and commercialization process in their respective institutions. This inclusion criteria for participant selection ensured that the study gathered insights from individuals with first-hand experience in Uganda's innovation and commercialization landscape. The sample included: a) 20–25 key informants (industry leaders, policymakers, TTO managers); and b) 2–3 focus group discussions with innovators and incubator managers.

#### ***3.5.2 Quantitative Sampling***

A stratified random sampling technique was used to obtain a representative sample calculated using a standard formula based on the expected proportion of innovative firms and a 95% confidence level. Strata were formed based on four categories of participants: a) knowledge generators, such as research institutions and universities; b) knowledge consumers, including techno-business firms and industry actors; c) support systems such as incubators, accelerators and innovation hubs; and d) government MDAs responsible for STI funding and policy formulation.

The target number of in-depth survey respondents and interview participants was determined using the following formula:

$$n = \frac{Z^2 \times [P \times (1-P)]}{\alpha^2} \quad (\text{Eqn. 1})$$

Where  $\alpha$  is the level of significance,  $e = 5\%$  [error],  $P = 0.917$  [% of innovative firms in Uganda] (NPA, 2020; Sithole, 2020), and  $Z = 1.96$  [ $Z$ -value].

$$\text{Taking } \alpha = 5\%, \text{ Thus } n = \frac{1.96^2 \times 0.62 \times 0.38}{0.05^2} = 362$$

Therefore, the sample size was 362 participants.

### **3.6 Data Collection Methods**

#### **3.6.1 Qualitative Data Collection**

Qualitative data was obtained through:

*Key Informant Interviews (KIIs):* Semi-structured interviews captured in-depth insights on innovation commercialization barriers, firm-level capabilities, institutional coordination, STI financing challenges, and policy implementation bottlenecks. The interview questions were designed to elicit participants' experiences, opinions, and expectations regarding innovation commercialization. Each interview session lasted approximately one hour and was conducted at different times and locations.

*Focus Group Discussions (FGDs):* This captured collective perceptions on; innovation ecosystem dynamics, university–industry–government linkages, and technology transfer processes. FGDs complement other qualitative methods by providing rich contextualized data that inform the understanding of systemic barriers, institutional coordination, and stakeholder collaboration. This collective approach strengthens construct development by triangulating findings with interview and document review data, thereby enhancing the robustness and depth of the analysis.

*Systematic Document Reviews:* This reviewed Uganda's NIS, utilizing the Scientific Procedures and Rationales for Systematic Literature Review (SPAR-4-SLR) protocol (Paul et al., 2021). This systematic evaluation was based on a wide range of sources, including national STI policies, R&D financing frameworks, innovation performance reports, and IP and technology transfer guidelines. This dual-pronged approach facilitated in-depth analysis of policy materials and empirical

evidence (Scheuer & Thaler, 2022), thus elucidating the complex dynamics of Uganda's NIS. The triangulated interview and systematic review data strengthened construct development.

*Delphi Technique:* This involved conducting multiple surveys with a team of experts (Spranger et al., 2022). After each round, the aggregated responses were shared with the panel to refine their views in subsequent rounds. This iterative process was designed to converge on a consensus regarding the most significant factors affecting innovation commercialization in Uganda, thereby addressing a critical gap in the existing empirical research.

### **3.6.2 Quantitative Data Collection**

A semi-structured questionnaire was developed based on constructs emerging from qualitative analysis and theoretical models such as NIS, Triple Helix, TRL, RBV, and dynamic capabilities. The questionnaire measured firm competencies, product–market alignment, institutional linkages, IP management, STI financing, policy coherence, market readiness, and commercialization outcomes. Responses were captured on a 5-point Likert scale ranging from a negative extreme (strongly disagree) to a positive one (strongly agree) to measure respondents' opinions. The research tool also combined a set of predetermined questions with the flexibility to ask follow-up questions based on Section 9.5 of the Oslo Manual Guidelines (OECD/Eurostat, 2018).

## **3.7 Data Measurement and Analysis**

### **3.7.1 Qualitative Data Analysis**

Qualitative interview data were analyzed using thematic analysis. Initial codes were generated from a sample of transcripts and iteratively refined as more data were processed. Specialized content analysis software (MAXQDA) facilitated coding, theme extraction, and generation of analytical results (Mihas, 2019; Lester et al., 2020). Documents were reviewed and synthesized to identify key stakeholders, contributing factors, and contextual elements that support innovation commercialization within the ecosystem. The data analysis process followed a structured, three-pronged approach (Mihas, 2019; Lester et al., 2020).

- a) *Data reduction*; Involved selecting, clustering, abstracting, and transforming interview transcripts into a manageable and useable format.
- b) *Data display*; Data were organized into time-ordered matrices and supplemented with contextual details to facilitate interpretation.

- c) *Drawing conclusions and verification*; Key results were evaluated and, where necessary, reanalyzed to confirm the findings.

A cross-case analysis was conducted using an explanation-building approach (Mihas, 2019; Lester et al., 2020) to deepen understanding of the similarities and differences among the case firms. This comparative technique helped to clarify the conditions under which various commercialization factors emerged. The cross-case methodology also enhanced the explanatory power and generalizability of the findings beyond single-case contexts, offering broader insights into innovation commercialization practices in techno-business enterprises.

### **3.7.2 Quantitative Data Analysis**

Descriptive statistics were used to summarize the participants' demographic characteristics and profile the respondents by sector, firm size, innovation activities, and experience. Exploratory Factor Analysis (EFA) was then applied to refine the constructs, identify the underlying commercialization factor structures, and validate the measurement items. The following key steps and considerations were undertaken during the EFA process:

- a) *Variable Selection*: This involved the selection of several variables to accurately represent each factor. Each factor is represented by multiple variables.
- b) *Factor Extraction*: This involved the extraction of the initial factors using the principal component analysis method through data reduction.
- c) *Factor Rotation*: This aimed to make factors more interpretable by correlating factors with each other (oblique rotation).
- d) *Eigenvalues*: This is a key indicator used to determine how many factors to retain. Factors with an eigenvalue greater than 1 are more stable and explain more variance
- e) *Interpretation*: After rotation, factor loadings were examined to determine which variables loaded strongly onto which factors. A meaningful conceptual label was then assigned to each factor.

Cross-tabulation was then applied to examine the relationships between emerging themes and quantitative indicators associated with innovation commercialization outcomes. The data were first cleaned and organized using Microsoft Excel before analysis using SPSS 26.0. Qualitative and quantitative data were analyzed concurrently but separately. Integration occurred during the

interpretation phase, where thematic findings from document reviews and interviews were used to explain and contextualize the relationships identified in the survey data.

### **3.8 Data Validity and Reliability**

The gathered data were transcribed, and the interpretations derived from the transcripts were shared with the respective participants for review. The participants were invited to evaluate the accuracy of the interpretations and offer clarifications or modifications where necessary. This process ensured that the captured information genuinely reflected the participants' views and experiences. Participants were allowed to correct any misinterpretations, thereby minimizing potential research bias and enhancing data credibility (Holliday, 2014). Data validity was maintained through: a) content validity involving expert reviews and qualitative grounding from KIIs, FGDs, and systematic document reviews; and b) construct validity involving assessing measurement tool accuracy regarding the theoretical concept under consideration. This study placed significant emphasis on ensuring the reliability and consistency of the data throughout the research process.

The proposed innovation commercialization framework was validated using the following criteria.

- a) *Coherence analysis*: This involved ensuring that innovation commercialization concepts are well-defined and that the relationships between them are clear and logical.
- b) *Exhaustiveness analysis*: This involved verifying that the innovation commercialization framework covered all relevant aspects of the problem (CVD).
- c) *Expert feedback*: This involved seeking input from experts in the field of innovation commercialization to assess the framework's validity and relevance.

### **3.9 Ethical Considerations**

The study relied on publicly available information such as academic publications, institutional reports, policy documents, and conference proceedings. No personally identifiable or sensitive information was collected from the participants. Where required, permission to access the library and institutional resources was obtained from appropriate authorities, such as department heads or organization leaders. The study involved interviews with personnel from various organizations and firms. All participants were informed about the study's purpose and potential benefits and were given the opportunity to withdraw at any stage. Oral consent was obtained from all participants

prior to the interviews, and the research was conducted in accordance with ethical guidelines and approved by the UNCST.

### **3.10 Chapter Summary**

This chapter presents the methodology adopted to develop and validate a context-specific commercialization framework for Uganda. The mixed-methods approach allowed the study to integrate deep qualitative insights with quantitative statistical rigor. The next chapter presents the results of the qualitative and quantitative analyses.

## CHAPTER FOUR: RESULTS

### 4.1 Introduction

This chapter presents the results of the study based on the sequential exploratory mixed-methods research design. The findings are organized into two major sections: (i) qualitative results from key informant interviews, focus group discussions, and document reviews, and (ii) quantitative results derived from the surveys. The synthesis of the seven papers reveals that Uganda's commercialization gap is not due to a lack of ideas, but rather a systemic failure characterized by fragmented actor linkages, misaligned R&D funding, and a critical lack of integrated support to bridge the CVD. These results contribute to new perspectives and address the gaps identified in the literature.

*Table 4.1: Relationship between the research questions and the appended papers*

Research question	Paper I	Paper II	Paper III	Paper IV	Paper V	Paper VI	Paper VII
RQ 1							
RQ 2							
RQ 3							
RQ 4							

This chapter links Papers I – VII to specific thesis objectives. Each objective was addressed in one or more papers. To address the aim of this study, this chapter synthesizes the findings of this thesis to answer the following research questions: the linkages and interrelationships between the actors in Uganda's NIS (RQ 1); the contribution of R&D funding and investment to innovation commercialization (RQ 2); the enabling conditions and barriers to innovation commercialization (RQ 3); and the interaction of the drivers of innovation commercialization at the firm, market, and policy levels (RQ 4). Consequently, it is structured according to the four research questions introduced in Chapter 1. To facilitate reading, the relationship between the research questions and the appended papers is presented in Table 4.1. The chapter concludes by presenting the validated integrative commercialization framework for Uganda.

### 4.2 Qualitative Results

#### 4.2.1 Overview of Participants

The qualitative phase included innovation-active firms, policymakers, university technology transfer officers, incubator managers, and senior researchers. The participants had direct

experience with commercialization, product development, STI policy implementation, and innovation ecosystem coordination.

#### ***4.2.2 Thematic Analysis***

Six major themes emerged from the thematic analysis.

*Fragmented Innovation Ecosystem:* Study participants consistently highlighted weak collaboration among the actors of the NIS. The key issues included siloed innovation initiatives, weak government, industry, academia coordination, and the absence of integrated databases for tracking innovations. These fragments directly contributed to duplication of efforts and slow commercialization processes.

*Limited Firm-Level Commercialization Capacities:* Firms expressed challenges related to low investment in R&D, limited product development expertise, weak market analysis skills, and inadequate IP management capability. Many firms lack specialized staff to coordinate commercialization or interact effectively with research institutions.

*Insufficient STI Financing and Funding Mechanisms:* Respondents highlighted the absence of dedicated commercialization funding instruments. The key concerns raised included limited government incentives, the absence of venture capital targeted at early-stage technologies, and minimal private investment in high-risk innovations. The financing gap was identified as a major contributor to CVD.

*Weak Policy Coherence and Implementation Gaps:* Participants noted that while Uganda has several STI policies, they lack synergy and predictable implementation. They cited the incomplete operationalization of national STI strategies, fragmented mandates across government MDAs, and delayed implementation of research funding initiatives. These inconsistencies undermine sectoral confidence and long-term innovation investment.

*Challenges in Achieving Market Readiness:* Innovations often fail to progress beyond pilot or prototype stages due to: lack of market validation, insufficient user engagement, and challenges in meeting certification and standards requirements. This theme reinforces the need for structured commercialization pathways.

*Need for a Nationally Integrated Commercialization Framework:* Stakeholders repeatedly emphasized the gap in a unifying commercialization framework that aligns firm competencies, innovation policy actions, institutional linkages, and STI financing mechanisms. These qualitative findings informed the constructs tested in the quantitative phase of the study.

#### ***4.2.3 Fragmented Innovation Ecosystem***

While the NIS's role in promoting economic growth is well recognized, a significant knowledge gap remains regarding how actor interactions and learning processes within these systems facilitate innovation commercialization in Uganda. This gap hinders the effective design and implementation of policies aimed at boosting innovation-driven development in emerging economies. When viewed in its entirety, the NIS can serve as a productive mechanism that facilitates the generation, development, and application of novel ideas and innovations to improve outcomes, processes, and services. Comprehending the intricate connections between institutional stakeholders engaged in innovation initiatives or procedures is vital for boosting a country's technical and economic performance. The NIS emphasizes the intricate relationships among national development actors, who constitute the foundation for a country's resilience, transformation, and sustainable development.

In Uganda, the NIS is a complex and diverse system that requires a comprehensive understanding of various influencing factors, including the effectiveness of STI policies, the level of social transformation, the human capital development index, and the factors, actors and constraints within the ecosystem. To ensure sustainable development, it is essential that actors within the ecosystem, such as the government, private sector, and civil society, engage in coherent and interconnected interactions. Additionally, the relationships between these actors and the broader socioeconomic and ecological contexts are crucial for the resilience and transformation of Uganda's NIS.

Paper I discusses the linkages and interrelationships among the actors in Uganda's NIS, as illustrated in Figure 1.1 (page 11). This modified conceptual framework highlights the essential conditions that shape Uganda's research, innovation, and commercialization ecosystem, including policy/regulatory, technical/technological, and market/economic contexts. The NIS framework encourages stakeholder collaboration and knowledge exchange to create, utilize, and monetize novel products, processes, and organizational strategies. This paper is premised on the notion that the NIS is a key component of Uganda's R&I landscape, bringing together various actors and

institutions involved in the country's transformation. The literature provides little guidance on the importance of interaction and learning among NIS actors in generating, applying, and commercializing new products, processes, and organizational strategies. While the NDP and Vision 2040 emphasize the use of the NIS as a guiding tool for fostering innovation and sustainable development, it has been subtly incorporated into Uganda's development process. This study highlights that the NIS directly affects interaction and learning among actors in the innovation ecosystem.

The study explored the relationships among NIS actors, offering insights into the utilization of Uganda's unique institutional and economic landscape for sustainable growth. It identifies key drivers, such as improved collaboration between the government, industry, and academia, and strategic policy measures in technology transfer and innovation funding, which are essential for revitalizing Uganda's innovation ecosystem. This study significantly advances our understanding of innovation systems by describing the intricate network of relationships within Uganda's NIS. This highlights the unexplored dimensions of learning and cooperation and thoroughly analyzes the factors that enable innovation, which are crucial for promoting innovation in developing countries. The study makes theoretical and policy contributions by highlighting the significance of NIS framework conditions in facilitating interaction and learning among actors in Uganda's NIS. Sufficient interaction and learning enhance a country's innovation, resilience, transformation, and sustainable development.

Collaboration and knowledge acquisition among actors within the NIS result in the advancement of products, processes, and organizational innovation. Figure 4.1 illustrates the framework conditions, key actors, and facilitating elements of the NIS. When conditions are conducive, interactions and learning occur among these actors, resulting in innovations that improve productivity, commercial viability, and profitability of R&I institutions. To achieve this, actors throughout the R&I ecosystem must grasp the processes of commercializing innovations and overcome barriers to technology adoption and commercialization.



**Figure 4.1:** *NIS framework conditions, key actors, and enablers*

While the significance of NIS in driving economic change has been recognized (Castellacci & Natera, 2013; Staniulyte, 2023), there is a substantial knowledge gap concerning how Uganda's distinct socio-economic and institutional environment influences the efficacy of NIS connections and the functions of various actors within the system. Existing research has largely neglected the influence of informal networks and local innovation cultures on the interactions between NIS actors in Uganda (Okumu & Buyinza, 2020; Salmon et al., 2020), which could provide valuable insights into enhancing ecosystems for long-term development. The study addresses these gaps by comprehensively examining the interactions, connections, and learning processes among the NIS actors in Uganda, emphasizing the impact of informal networks and indigenous innovation methods. Bridging these knowledge gaps is crucial for developing more effective policies and strategies that capitalize on local strengths and cultural practices to foster innovation, potentially leading to more robust and sustainable development outcomes.

#### **4.2.4 Insufficient STI Financing and Funding Mechanisms**

The GOU has prioritized STI in its pursuit of a knowledge-based economy (NPA, 2020). While scholars have acknowledged a positive correlation between investment in innovation and improved performance (Zhu et al., 2020; Hussen and Çokgezen, 2021), the specific role of R&D grants and investments in innovation commercialization and their impact on innovation performance requires further exploration. The global competitive landscape is increasingly centered around scientific and technological capabilities.

**Table 4.2: Selected national R&D grants and investment projects at UNCST**

<b>R&amp;D grant and investment projects</b>	<b>Implementation period</b>	<b>Partners</b>	<b>Impact areas</b>
Millennium Science Initiative (MSI)	2007 - 2013	World Bank, GOU	Research infrastructure and human capital capacity development
Government Support to Scientists (GSS) Initiative	2005 - 2014	GOU	Scientific innovations and products in malaria control, banana value addition, ICT, and material science
National Science, Technology, and Innovation Programme (NSTIP)	2015 - 2016	GOU	R&D products for commercialization and industrial application
Innovation Fund	2017 - 2018	GOU	Generating and applying new knowledge to development challenges
Science Granting Councils Initiative (SGCI) in Sub-Saharan Africa	2014 – to date	IDRC, DFID, NRF, SIDA	Policy analysis, M&E, grants management, partnerships/collaborations, collaborative research grants
Eastern Africa Regional Research Network for Biotechnology, Biosafety, and Biotechnology Policy Development (BIO-EARN)	1999 - 2005	SIDA, GOU	Develop capacity and competencies to use effectively and integrate modern biotechnology
Coordination and Advancement of Sub-Saharan Africa-EU Science & Technology Cooperation Network (CAAST-NET)	2014 - 2020	EU, GOU	Advancement of STI cooperation in research and innovation
Bio-resource Innovations Network for Eastern Africa Development (Bio-Innovate)	2010 - 2014	SIDA, GOU	Initiation, intensification, and dissemination of innovations for sustainable utilization, transformation, and integration
Development Research Uptake in Sub-Saharan Africa (DRUSSA)	2012 -2015	DFID	Capacity building in evidence-based policymaking

Uganda's domestic economic development is steadily shifting from investment- and factor-driven to innovation-driven. In line with this transition, the GOU has continued to increase investment in research, technology, and innovation. According to data from the Uganda Bureau of Statistics (UBOS), the number of full-time equivalent (FTE) R&D personnel has grown by approximately 3,000 individuals annually over the past five years. R&D expenditure as a percentage of GDP

increased from 0.37% in 2002 to 0.41% in 2009 (UBOS, 2020; UNCST, 2016a, 2016b). Over the same period, government grants increased from 183.3 billion to UGX 301.32 billion. In alignment with the targets outlined in NDP III, the national expenditure on R&D is expected to reach 1% of GDP by 2030 (NPA, 2020; Sithole, 2020).

Paper III examines the contribution of R&D funding and investment to the commercialization of innovations in Uganda. This study highlights selected national R&D grants and investment projects (Table 4.2) and their impact. The UNCST Act provides the legal framework for the establishment of the Science and Technology Fund, which governs the management of R&D funds (GOU, 1990). The UNCST effectively managed the MSI funding facility, an initiative co-funded by the World Bank and the GOU (Crawford et al., 2006), and its successor, the NSTIP grant facility, following global best practices in grant management. Other development partners, such as the European Union, Third World Academy of Sciences (TWAS), and International Foundation for Science (IFS), have also managed their research grants through the UNCST Grants Management Facility. This study evaluates the contribution of R&D funding and investment to the commercialization of innovations in Uganda. It highlights the selected national R&D grant schemes and investment projects (Table 4.2) and assesses their impact.

Numerous studies have demonstrated the existence of externalities in technological innovation in Uganda (Ecuru et al., 2014; Mulumba et al., 2017; Fashina et al., 2018; Kwesiga, 2019). The dissemination of information and technology and the likelihood of competitors imitating these advancements inevitably affect inventors' excitement towards innovation. This is detrimental to the overall progress of technological innovation. Therefore, governments must implement incentives to encourage innovation and enhance technological R&D. For example, the government subsidizes R&D and provides tax relief through grants. However, these subsidy strategies do not yield the desired outcomes. The reasons for this failure include beneficiaries' preferences for government R&D funding, rent-seeking, and fraudulent practices of R&D subsidy recipients. Thus, enhancing R&D fund effectiveness remains a challenge. Therefore, analyzing government subsidies and their influence on innovation is crucial for boosting national and firm innovation and providing effective government subsidies. Paper III discusses R&D grants and investment impact analysis in the private, industrial, agricultural, energy, education, health, and ICT sectors (Table 4.3).

**Table 4.3: R&D grants and investment impact analysis in key sectors in Uganda**

<b>Sector</b>	<b>Intervention/Impact</b>	<b>Description</b>
Private	Development of Pamoja Clean Technologies	<ul style="list-style-type: none"> <li>▪ Utilizes the power pallet gasifying corncobs as a foundation for developing a range of energy services</li> <li>▪ Provides rural decentralized renewable energy solutions</li> </ul>
	Development of low-cost sanitary pads ‘Makapads’	<ul style="list-style-type: none"> <li>▪ Low-cost sanitary products made from papyrus and paper, resulting in a cost reduction of approximately 50%</li> <li>▪ Makapad’s innovation addresses the issue of school absenteeism due to menstruation, as many girls cannot attend classes during this period.</li> </ul>
	Development of Fresh Vacuum Sealed Matooke ‘FREVASAMA’	<ul style="list-style-type: none"> <li>▪ Value-added bananas (Fresh Vacuum Sealed Matooke), which can remain fresh for up to six months in a frozen state</li> <li>▪ Exported and available in the major supermarkets in Uganda</li> </ul>
Industry	Rehabilitating and equipping of UIRI	<ul style="list-style-type: none"> <li>▪ Mechanical engineering department, including basic computer-aided design and manufacturing services</li> <li>▪ Industry resource centres, industrial equipment, and machinery that provide practically oriented training for technicians</li> <li>▪ Technology development centre, which now produces food-grade enzymes, electronics, and renewable energy system products</li> <li>▪ Vaccine plant, microbiology, and chemistry laboratory</li> <li>▪ Business development centre and pilot plants with an average of 30 projects under incubation</li> </ul>
Agriculture	Development of sustainable agri-based solutions	<ul style="list-style-type: none"> <li>▪ Development of cassava variants with resistance to cassava brown streak disease</li> <li>▪ Propagation of catfish and the Nile perch under cultivation conditions to support the fish farming industry</li> <li>▪ Development of new techniques for assessing climate variability, environmental degradation, and lake level dynamics of Lake Victoria</li> <li>▪ Development of molasses urea blocks to improve milk and meat production in livestock</li> <li>▪ Banana rapid multiplication products and protocols</li> <li>▪ Novel diagnostic tools for domestic animals and poultry</li> <li>▪ Vaccines and research products that control tropical parasitic diseases of livestock</li> </ul>

Energy	Development of efficient and sustainable energy sources	<ul style="list-style-type: none"> <li>▪ Technology transfer and commercialization of charcoal (briquettes) manufacturing technology to farmers and entrepreneurs</li> <li>▪ Development of micro-enterprises and marketing of the briquettes, emphasizing the environmental concerns associated with using wood charcoal</li> </ul>
Education	Training and development of university programmes	<ul style="list-style-type: none"> <li>▪ Training of 3660 scientists and engineers, with 57 at MSc and 31 PhD levels</li> <li>▪ Initiation of four new undergraduate courses in science, technology, and engineering (STE) and the upgrading of seven STE courses; these include i) Surveying and Land Economics at Makerere University, ii) Biosystems Engineering at Gulu University, iii) Pharmaceutical Sciences at Mbarara University of Science and Technology, iv) Science Teacher Training programs at Kabale University, v) Biotechnology at Makerere University, vi) E-education Program at Kyambogo University, and vii) Textile Engineering at Busitema University</li> </ul>
Health	Development of anti-malaria herbal drink 'Artavol'	<ul style="list-style-type: none"> <li>▪ Malaria-prevention herbal drink available in pharmacies in Uganda</li> <li>▪ Consumed as a beverage or functional food to prevent frequent fever and worm infestations and possesses antioxidant properties</li> <li>▪ This prophylactic medicine has proven to be effective in preventing malaria</li> </ul>
ICT	<p>Development of a disease diagnosis and drug stock control system</p> <p>Investment in computer-based management</p> <p>Piloting the multi-purpose rural telecenter model</p>	<ul style="list-style-type: none"> <li>▪ Disease diagnosis and drug stock control system in pharmaceutical and medical supply management, patient-centred health management informatics systems, health staff management, and hospital administration</li> <li>▪ Automated Cargo and Vehicle Management (ACRAV) system providing a collaborative portal that brings transit companies and agents together, thereby increasing visibility and freight control</li> <li>▪ Established three telecenters in rural and peri-urban areas in Uganda, located in Nabweru, Buwama, and Nakaseke</li> <li>▪ These telecenters serve as access points and demonstration centres for rural communities on a range of ICTs</li> </ul>

The study findings highlight the need for GOU to prioritize institutional development, address structural problems to innovation input, promote talent flow, and rationally build regional knowledge value chains to improve innovation and commercialization efficiency. The UNCST

must maintain momentum in gathering STI indicators to support the evidence-based formulation of effective STI policies. This study provides theoretical and policy-oriented insights by emphasizing the significance of R&D funding and investment in facilitating innovation commercialization in Uganda.

#### ***4.2.5 Limited Firm-Level Commercialization Capacities***

Limited firm-level commercialization capabilities in Uganda significantly hinder the successful transition of innovations from prototypes to the market. Many firms face challenges related to inadequate technical skills, insufficient expertise in product development, weak market analysis, and poor intellectual property management. These deficiencies reduce competitiveness and constrain firms' ability to effectively position their innovations in the market, limiting their capacity to create unique value propositions and respond to customer needs. The Resource-Based View (RBV) underscores that internal firm capabilities, such as R&D strength, entrepreneurial knowledge, and commercialization management, are critical determinants of innovation success; however, these remain underdeveloped in many Ugandan techno-business firms. Consequently, firms often lack specialized personnel to coordinate commercialization activities or effectively engage with research institutions and market actors. Addressing these capability gaps through targeted capacity building, strategic business model development, and enhanced collaboration with support institutions is essential to improve commercialization outcomes and bridge the persistent commercialization valley of death in Uganda's innovation ecosystem.

Techno-business firms in Uganda significantly influence the country's innovation landscape by contributing to incremental and adaptive innovations. The potential of these firms has not been fully realized because of inadequate engagement with research institutions and an underdeveloped commercialization ecosystem. To address this issue and facilitate technology transfer and entrepreneurship, it is essential to fortify collaboration among firms, universities, and policy mechanisms. Noya and Taneo (2023) emphasized the importance of strengthening these interactions to enhance innovation output. Additionally, improved interactions with knowledge-intensive services are crucial for fostering innovation in these firms.

Techno-business firms typically face intense competition and must develop suitable business models to effectively commercialize new products and realize their economic potential. In emerging economies, technological entrepreneurship is fostered through connections between

significant technology firms and small enterprises, thereby contributing to industrial growth (Usman et al., 2024). A firm with specialized technological capabilities may choose to commercialize its products alone or adopt a hybrid strategy depending on competition and financial position. Research has shown that open innovation business models are positively associated with successful technology commercialization, suggesting that being open can lead to shorter development times and a more significant proportion of sales from new products.

#### ***4.2.6 Challenges in Achieving Market Readiness***

Effective product positioning depends on choosing the right strategy based on the target audience and competition. A clear and concise marketing message that communicates the positioning strategy is essential. It is crucial to ensure consistency across all marketing materials, including websites, packaging, and advertising. A combination of online and offline marketing methods, such as social media, websites, print media, television, trade exhibitions, and relationships with influencers and industry leaders should be used to reach the target audience.

It is important to use case studies, testimonials, and certifications to demonstrate a firm's expertise, record achievements, and industry knowledge. Additionally, analyzing competitors' strengths and weaknesses can help identify market gaps and differentiate a firm's products or services. Developing a unique value proposition and effective branding and marketing plans is essential for setting a firm apart from its competitors. This involves creating a strong brand identity and consistently communicating key messages across all marketing channels.

Standards are essential for businesses to market and innovate efficiently. They ensure that products, systems, and services work together and establish technological requirements and protocols that allow seamless integration between businesses. By fostering collaboration and reducing redundancy, standards promote innovation and help organizations focus their resources on creating new solutions rather than upgrading existing ones. This leads to faster time-to-market for new products and services.

This study examined the role of the private sector, availability of support infrastructure, and financial mechanisms in R&I institutions. Key barriers include ecosystem fragmentation, inadequate infrastructure (e.g., technology transfer offices), and limited innovation financing. The interplay of these barriers creates a vicious cycle: fragmentation prevents coordinated

infrastructure investment, and the lack of infrastructure scares away the financiers needed to overcome fragmentation. These challenges highlight the urgent need for targeted policy interventions that address systemic, infrastructural, and financial constraints (Figure 4.8). The private sector plays a crucial role in commercializing innovations that are vital to national development. Recognizing this, the GOU has introduced initiatives to create a supportive business environment.

A significant knowledge gap exists regarding how ecosystem fragmentation affects resource allocation and information dissemination (Okumu & Buyinza, 2020). This study found that fragmentation is a major systemic challenge. It evaluated the linkages between knowledge producers (e.g., universities, research institutes, and NGOs) and users (e.g., techno-business firms) and concluded that sector-wide integration is essential. Sectoral fragmentation measures must be implemented across the R&I system to enhance the effectiveness of these linkages and cooperation.

#### ***4.2.7 Weak Policy Coherence and Implementation Gaps***

Research and innovation (R&I) institutions must commercialize their innovations to remain competitive in the knowledge-based economy. While R&I institutions in Uganda have the potential to contribute to socio-economic development, a clear understanding of the commercialization pathway remains elusive. Although previous studies have emphasized the importance of innovation commercialization in driving economic growth and transformation in developing countries (Shcherbachenko & Kotenko, 2022; Butnik-Siverskyi et al., 2024), there is limited understanding of the systemic, infrastructural, and financial challenges specific to Uganda's R&I institutions. In contrast to earlier research that examined these dimensions separately, this study adopted a comprehensive approach that integrated all three.

Ecuru et al. (2014) noted systemic barriers in Uganda's commercialization process; however, detailed insights into these barriers remain scarce. This study explored these issues in depth. A lack of understanding of the structure and functionality of Uganda's innovation and commercialization systems hinders investment in R&I, and affects stakeholder engagement and collaboration within the ecosystem. Consequently, policymakers are constrained in their ability to develop and implement effective strategies for advancing innovation and commercialization

systems. This results in underutilized R&I programs, the value and impact of which are frequently underestimated.

Paper IV identifies the drivers and barriers to innovation commercialization at R&I institutions in Uganda. Effective commercialization contributes to national transformation, competitiveness, and sustainable development. When conditions are conducive, interactions and learning among actors enhance productivity, commercial viability, and profitability. Overcoming barriers to commercialization requires a comprehensive understanding of innovation processes and the roles of all actors in the ecosystem.

**Table 4.4: Barriers to innovation commercialization in the research and innovation sector**

<b>Intervention</b>	<b>Type of Organization</b>					
	<i>University</i>	<i>Public research institute</i>	<i>NGO</i>	<i>Private company /Firm</i>	<i>Consultancy firm</i>	<i>Other</i>
Presence of private sector collaboration	Yes	Yes	Yes	Yes	Yes	Yes
Availability of institutional R&D infrastructure	Yes	Yes	No	Yes	No	No
Presence of intellectual property and technology transfer offices	Yes	Yes	No	No	No	No
Presence of institutional intellectual property policies	Yes	Yes	No	No	No	No
Presence of grants management offices	Yes	Yes	No	Yes	Yes	No
Allocation of resources to institutional innovation and commercialization activities	Yes	Yes	Yes	No	No	No

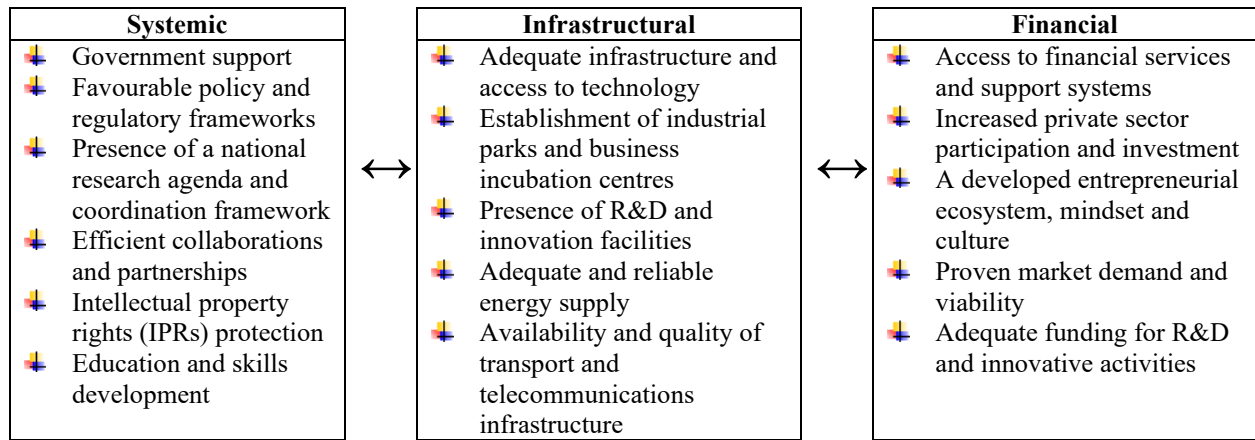
Except for limited responses from recently established institutions, all participants reported private sector participation in their organizations' operations (Table 4.4). Few institutions that did not involve the private sector in their operations were situated upcountry and geographically removed from the country's major business centre, which hosts a higher concentration of private firms and corporations. Some of these institutions were new and still in the early stages of establishing their operations, hindering their ability to collaborate and interact with the private sector. Only private enterprises, research institutions, and universities reported having sufficient institutional infrastructure in the form of laboratories, incubation centres, and workshops (Table 4.4). The

respondents cited reasons such as the lack of funding and resources for development, and the obsolescence of some equipment and technologies in innovation and incubation facilities for those where the support infrastructure was deemed insufficient.

IPMOs and TTOs work together to safeguard and promote innovative ideas. TTOs facilitate collaboration between academia, research, and the business sector, enabling technology and knowledge exchange. IPMOs specialize in the legal aspects of IP generation, protection, and licensing, and their cooperation is essential for the successful commercialization of discoveries and their transformation into practical products, services, and economic value. As shown in Table 4.4, TTOs and IPMOs were primarily observed in universities and public research institutions. This deficiency in promoting innovation and commercialization was identified in private corporations, consulting firms, and NGOs. Universities and public research institutions with TTOs and IPMOs implemented IP policies. This is because universities and research organizations need a structured approach to manage the IP assets generated by their R&D outputs. To promote innovation and commercialization, all institutions must embrace IP policy development.

Table 4.4 illustrates that universities, research institutes, private companies, and consultancy firms have established GMOs to manage their funding. In contrast, NGOs are less likely to have GMOs because they frequently receive financing from parties whose agendas they advocate. Consequently, having a GMO may not be a priority for these organizations, as they do not require external funding to support their activities. Most participating R&I institutions, except for certain universities, research institutes, and private enterprises, reported committing resources to support commercialization efforts. These institutions primarily consisted of private and research organizations that aimed to generate revenue through education and training by committing resources to support commercialization efforts.

Uganda's R&D infrastructure remains underdeveloped, with limited access to laboratories and research facilities. A detailed assessment of resource allocation could inform strategic investments in critical infrastructure, including incubators and technology transfer offices (Pius & Owin, 2024). Despite progress through innovation centres and incubators. While existing support systems help translate ideas into marketable products, budgetary constraints limit their functionality, especially in Intellectual Property Management Offices (IPMOs), Technology Transfer Offices (TTOs), and Grant Management Offices (GMOs).



**Figure 4.2:** Systemic, infrastructural, and financial drivers that influence the commercialization of innovations

This study examined the role of the private sector, availability of support infrastructure, and financial mechanisms across R&I institutions. Key barriers include ecosystem fragmentation, inadequate infrastructure (e.g., technology transfer offices), and limited innovation financing. These challenges highlight the urgent need for targeted policy interventions that address systemic, infrastructural, and financial constraints (Figure 4.2). The private sector plays a crucial role in commercializing innovations that are vital to national development (Abbas et al., 2019; Kruachottikul et al., 2023). Recognizing this, the Government of Uganda (GOU) has introduced initiatives to create a supportive business environment (Okumu & Buyinza, 2020; Sendawula et al., 2023).

Innovations remain underfunded, particularly in the early stages of development. Uganda's financial sector lacks robust venture capital and investor networks, and entrepreneurs often lack the financial literacy required to manage resources effectively. Comparative insights from Kenya's mobile technology sector highlight the possible public-private funding models that Uganda could adopt (Atwine et al., 2023). The study assessed institutional funding mechanisms, the performance of GMOs, and resource accessibility, revealing weak financial systems as a major barrier. To address funding gaps, options such as pooled resources and joint ventures should be explored. Overall, this study underscores the need for an interactive R&I ecosystem supported by institutional and national-level mechanisms. Recommendations include establishing a national innovation fund, strengthening public-private R&D infrastructure partnerships, and adopting cohesive policy frameworks. These efforts will facilitate commercialization and catalyze innovation in Uganda's R&I institutions.

Idea commercialization often requires significant capital investment and the establishment of financing mechanisms for innovation and commercialization. The evaluation of these mechanisms in various organizations was conducted using factors such as the effectiveness of GMOs, institutional allocation of resources, accessibility to innovation and commercialization resources, and the competencies and skills of GMOs. The study found that the lack of dependable institutional finance systems for research, innovation, and commercialization is a significant obstacle to innovation commercialization in Uganda. According to this study, insufficient financing impedes the growth of Uganda's research and innovation (R&I) ecosystem. This study analyzed the allocation and availability of financial resources for innovation and commercialization in Ugandan R&I institutions. The successful implementation of innovation and commercialization initiatives is vital for a country's economic development, and financial sustainability is crucial in determining their success. To address existing funding gaps in R&I institutions, this study recommends exploring options such as pooling resources or establishing joint ventures.

The study's results highlight the need for an interactive R&I ecosystem and the availability of support mechanisms at both the institutional and national levels. To address these barriers, this study recommends that the government and partners should encourage interaction and learning among R&I ecosystem players, improve R&D infrastructure, and boost innovation and commercialization finance channels. Based on our findings, we recommend establishing a national innovation fund, enhancing public-private partnerships for R&D infrastructure development, and formulating a cohesive national policy framework to streamline commercialization processes at R&I institutions. This study provides policymakers with a data-driven foundation to craft targeted interventions and remove the identified barriers, thereby catalyzing innovation commercialization in Uganda's R&I institutions. This study contributes to the empirical theory or explanation of the systemic, infrastructural, and financial drivers and associated measures that influence the commercialization of innovations at R&I institutions in Uganda.

#### ***4.2.8 Need for a Nationally Integrated Commercialization Framework***

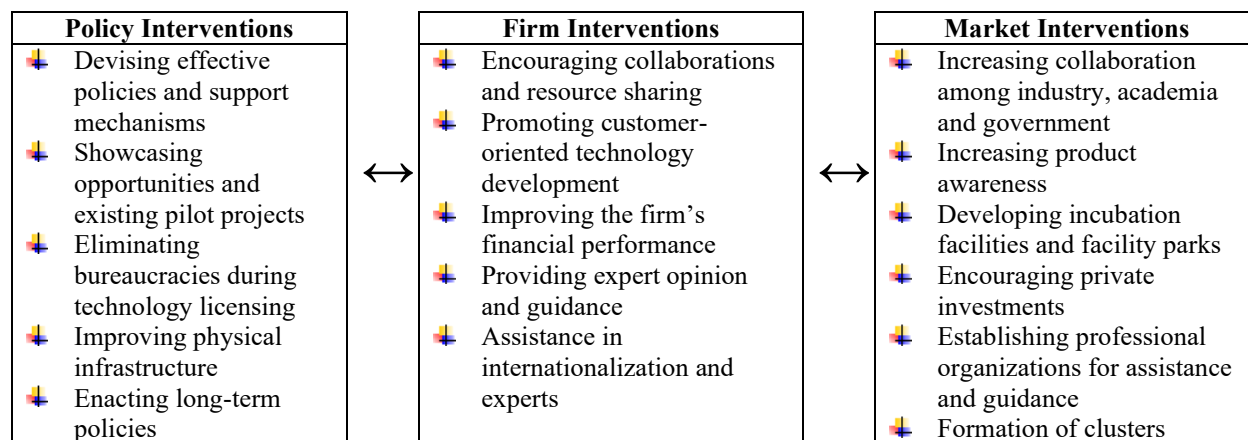
In response to the multi-level barriers identified in the previous sections, this study consolidates its findings into a comprehensive model framework for innovation commercialization in Uganda. This framework, detailed in Paper VII, is designed specifically to integrate strategies across the firm, market, and policy levels to bridge the CVD. The tri-level (firm, market, and policy) structure

of the framework is the core innovation of this study, directly addressing the identified gap in the literature for an integrated approach. Uganda's innovation potential is significant, but transitioning from prototypes to marketable products remains a challenge, contributing to the commercialization valley of death (CVD).

Despite considerable attention to commercialization processes, a unified framework has not yet been reported in the literature. A successful commercialization process is crucial for unlocking the full potential of innovation, as demonstrated by the commercial success of products and their strategic significance in driving economic growth and development. The lack of information about a country's innovation and commercialization processes hinders effective investment in STI. This impedes the ability of policymakers and other stakeholders to develop initiatives that promote growth. This can result in underutilizing well-intentioned STI programs and underestimating the value, relevance, and impact of technological innovation programs.

The firm's contributing factors play a pivotal role in innovation commercialization, as they directly impact a firm's ability to introduce new products, services, or technologies to the market. The influence of market-contributing factors on the commercialization of inventions is substantial, as they pertain to understanding and fulfilling the demands and preferences of the target market. They guarantee that innovation has a viable market and effectively fulfills customer requirements. Policy contributing factors significantly affect innovation commercialization. These factors affect the regulatory and business environments in which firms operate and can either speed up or slow down the process of bringing ideas to the market.

Although previous research has examined the influence of government support on innovation, there remains a significant gap in understanding how firm-specific elements such as internal resource allocation and innovation management strategies contribute to overcoming CVD in Uganda. Moreover, the impact of market forces unique to developing economies on CVD has not been thoroughly investigated. Uganda presents a distinctive opportunity to study CVD in the context of its emerging technological landscape. In contrast to established markets, Ugandan techno-business firms encounter specific market-related challenges, including low consumer familiarity with novel technologies and a dynamic regulatory environment that may exacerbate CVD.



**Figure 4.3:** Intervention framework at policy, firm and market levels to bridge the commercialization valley of death

Bridging CVD relies on sustainable financial systems, effective partnerships and collaborations, strong global linkages, and the availability of R&D infrastructure. For instance, a techno-business startup that develops low-cost solar-powered water pumps must navigate market dynamics, leverage R&D infrastructure, demonstrate technological expertise, raise product awareness, and comply with government regulations. This study proposes actionable interventions (Figure 4.3) at the policy, firm, and market levels to bridge the CVD. By highlighting these interventions, this study provides valuable theoretical and policy insights that can guide the development of targeted interventions to foster technopreneurship and innovation commercialization in Uganda. Ultimately, this study presents a solution that firms can implement to improve the benefits of innovative technology and product development to achieve commercial gains and overall economic growth. This would generate transformational development by increasing industrial output and strengthening the linkages between researchers, innovators, and the private sector.

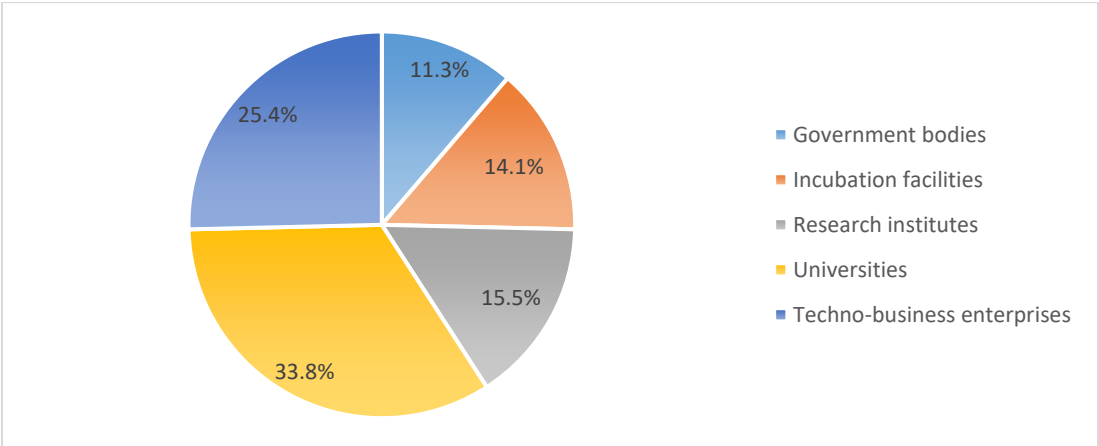
The specific mechanisms through which government policies and support systems influence the commercialization process in Uganda's unique socioeconomic environment remain underexplored. Similarly, while firm-specific factors such as organizational culture and technology transfer practices are known to affect commercialization success, their specific manifestations and effects within Ugandan techno-business firms have not been thoroughly detailed. Although studies such as Helman (2023) and Kesselring et al. (2023) have highlighted the role of market demand and strategic partnerships in overcoming CVD in developed countries, there is a gap in understanding how these factors play out in the Ugandan context, where market dynamics and innovation ecosystems may differ significantly. The literature lacks a comprehensive theoretical framework

that integrates market dynamics, government policies, and firm-level strategies in developing countries, such as Uganda. Therefore, this study uses a specific theory or model to examine the determinants of CVD among Ugandan techno-business firms and addresses a critical gap in the literature.

### 4.3 Quantitative Results

#### 4.3.1 Demographic Characteristics of Participants

The quantitative phase encompassed a diverse range of organizations, including techno-business firms (25.4%), universities (33.8%), research institutes (15.5%), incubation centers (14.1%), and government agencies (11.3%). This information is illustrated in Figure 4.4.



**Figure 4.4:** Organizations as a proportion of the total study participants

The key demographic characteristics included sector distribution (ICT, manufacturing, agriculture, health, and energy), firm size (micro, small, medium, and large), years of experience in innovation activities, and role in commercialization (R&D, innovation management, policy, and entrepreneurship). This ensured representation across the entire innovation ecosystem in the country.

#### 4.3.2 Micro-Level Drivers

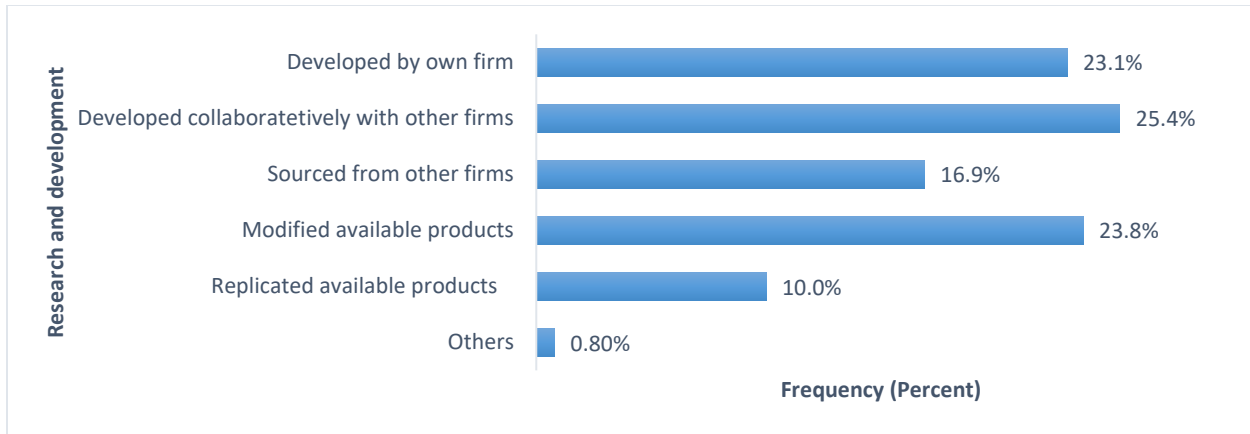
This study sheds light on how techno-business firms drive innovation and commercialization in Uganda (Table 4.5) by examining the various factors that influence the growth of these firms, such as their approaches to R&D, marketing, and partnerships.

**Table 4.5: Firms' innovation and commercialization activities**

<b><i>Innovation and commercialization activities</i></b>	<b>Percent (%)</b>
Research and development	24.6
Intellectual property protection	17.7
Employee training	16.5
Marketing and brand equity	13.7
Innovation management	10.5
Engineering, design, and other creative works	6.9
Software and database development	4.8
Acquisition or lease of tangible assets	4.4
Others	0.8

Several firms (24.6%) reported that R&D is critical to their innovation and commercialization efforts (Table 4.5). R&D is crucial for driving innovation within a firm by conducting systematic research, experimentation, and inventing new products, processes, and services. R&D investments enable firms to remain competitive, adapt to market changes, and develop innovative solutions to meet customer needs. The study indicates that only a small proportion (4.4%) of firms acquired or leased tangible assets (Table 4.5). This surprisingly low figure (4.4%) indicates that even innovative firms may struggle with capital expenditures for scaling, potentially trapping them in the prototype phase and exacerbating CVD. By exploring new technologies and emerging trends, firms may discover untapped or specialized markets. Learning about customer preferences, behaviour, and future demands through market research helps firms leverage emerging trends and expand their businesses.

The study results indicate that conducting R&D and protecting IP (17.7%) are vital to firms' innovation and commercialization initiatives (Table 4.5). This study underscores the importance of grants and subsidies as primary financing mechanisms for firm activities. This highlights that product or innovation development depends on collaborative agreements, adjustments to current products, and internal idea generation. Furthermore, the paper reveals innovation and commercialization disparities and proposes remedies to bridge these gaps. This fosters transformative growth by enhancing industrial production and strengthening the connections between techno-business firms and the industrial sector.



**Figure 4.5:** *Firms' product or innovation development activities*

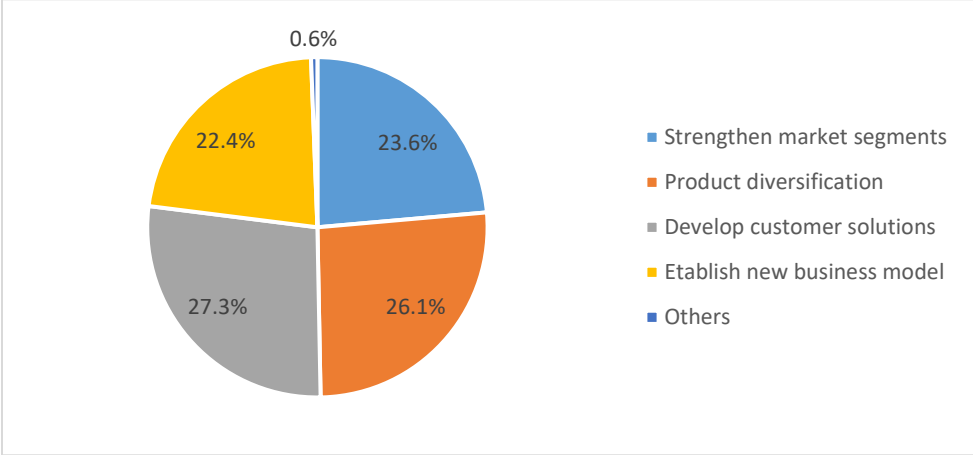
This study explored the influence of product innovation development on a firm's competitive advantage, customer satisfaction, market expansion, revenue growth, brand image, market adaptation, and talent recruitment, as outlined in Section 6.3.2 of the Oslo Manual (OECD/Eurostat, 2018). Allocating resources for product development and commercialization can help firms achieve long-term success in competitive markets. As shown in Figure 4.5, a significant number of firms reported creating products or innovations through collaborative agreements with other firms (25.4%), modifying existing products (23.8%), and modifying their initial concepts (23.1%).

Developing exceptional products can differentiate firms from their competitors by providing a competitive edge that aids in attracting and retaining clients, expanding market share, and staying ahead of the market. Continuous improvement and innovation that meet or surpass customer expectations and enhance customer satisfaction are essential. Firms can foster increased customer loyalty and repeat business through improved products and services by effectively addressing customer needs. The survey results (Figure 4.5) indicate that firms face issues such as product duplication (10%) and a heavy reliance on external ideas, concepts, and information (16.9%). Product development innovation allows firms to explore new markets and customer segments by creating and commercializing new products.

### **4.3.3 Macro-Level Enablers**

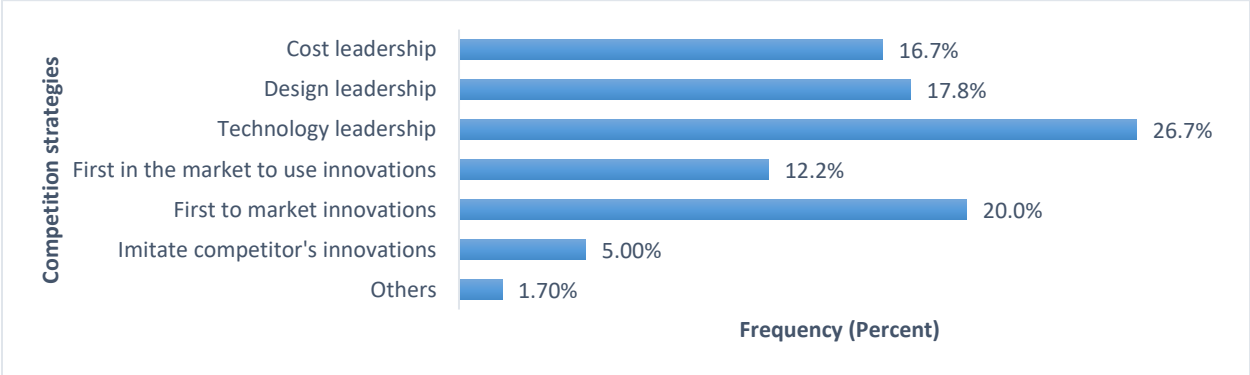
Product positioning evaluates customer perceptions of a firm's offerings relative to its competitors. This involves highlighting the firm's beliefs, goals, and vision and demonstrating how its products or services address customer needs and enhance their lives. As shown in Figure 4.6, firms employ

various techniques to position their products in the market, such as tailoring solutions for specific customers (27.3%), diversifying or expanding product lines (26.1%), strengthening their positioning in distinct market segments (23.6%), and developing new business models (22.4%).



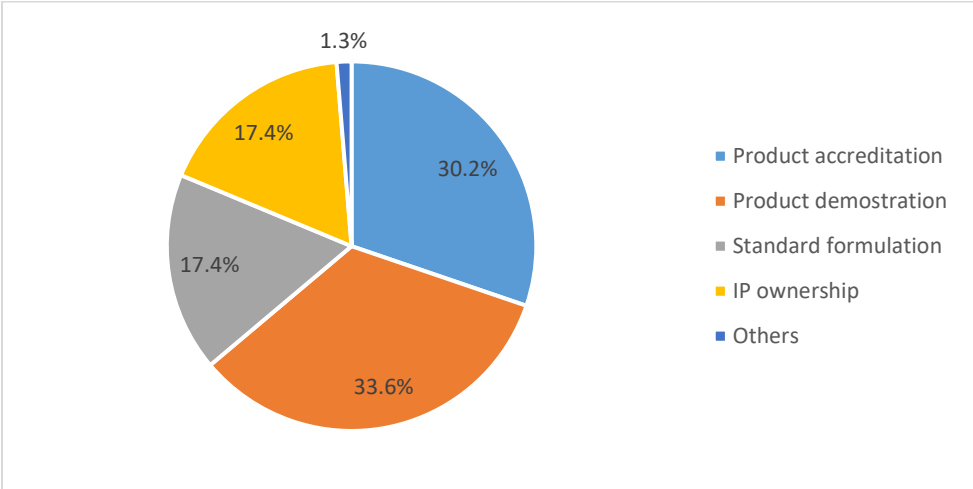
**Figure 4.6:** Firm strategies to position its products on the market

To effectively compete in the market, firms must understand their target audience and unique value propositions, as outlined in Section 8.2 of the Oslo Manual (OECD/Eurostat, 2018). This involves identifying the target market, customer needs, and pain points. Firms can then develop a positioning strategy that aligns with their market's unique requirements by gaining insight into their customers. The survey revealed that firms use various strategies to compete, such as offering technological leadership (26.7%), first-to-market product or service innovation (20%), design leadership (17.8%), and cost leadership (16.7%). Replicating competitive ideas (5%) and being the first to adopt product advancement in the market (12.2%) were the least effective strategies (Figure 4.7).



**Figure 4.7:** Firm strategies to counter its competitors

This study examined the role of standards in aiding firms in effectively navigating markets, fostering innovation, improving interoperability, managing risks, and expanding their reach. Firms can increase their growth, competitiveness, collaboration within markets, and innovation by adhering to and actively participating in standardization efforts.

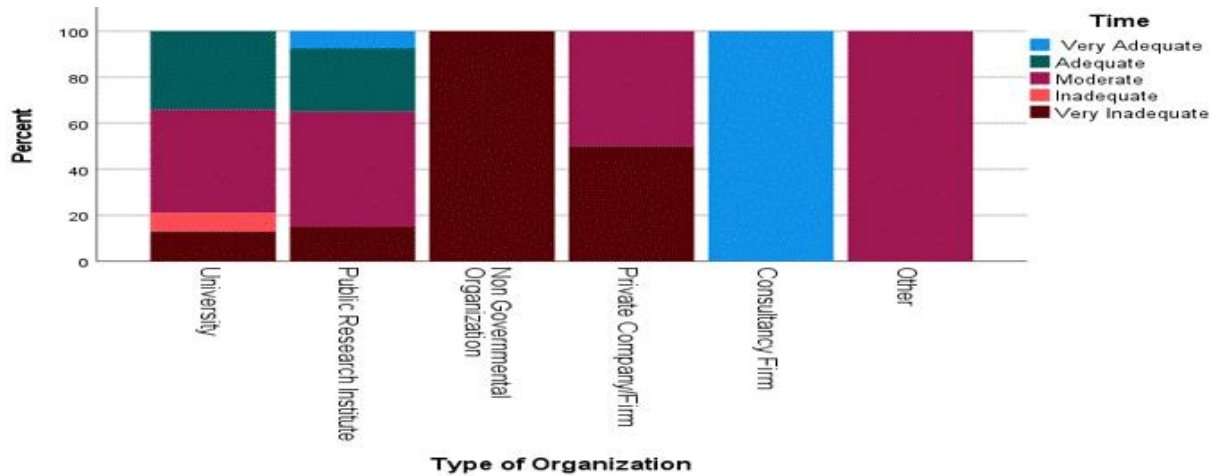


**Figure 4.8:** Role of standards in the firms’ markets and innovation activities

The survey results indicate that 33.6% of the participating firms found standards useful for demonstrating the quality of their goods or innovations, while 17.4% considered them necessary to promote the involvement of enterprises in developing industry standards and owning IP rights (Figure 4.8).

**4.3.4 Innovation Commercialization Mediating Interactions**

Several scholars have noted the importance of allocating time for collaboration with the private sector to commercialize innovation (Salmon et al., 2020; Stubbs et al., 2022). The private sector plays a crucial role in economic growth, job creation, and the introduction of new products and services into the market. By working together, the public and private sectors can expedite the innovation process, leading to increased productivity, competitiveness, and societal benefits. According to the study, private sector collaboration was found to be highly valued in the commercialization of R&D, but most R&I institutions did not allocate sufficient time to promote such collaborations. Consultant firms were an exception, as they dedicated sufficient time to private sector collaboration, as illustrated in Figure 4.9.



**Figure 4.9:** Time dedicated to private sector collaboration

The study also revealed that consultancy firms spent the most time collaborating with the private sector, followed by universities, and research institutes. In contrast, NGOs and private corporations were less dedicated to collaborating with the private sector. The limited commitment of NGOs to private sector collaboration can be attributed, in part, to their funders, who often have special interests and restrict NGOs' participation in private sector players to some extent.



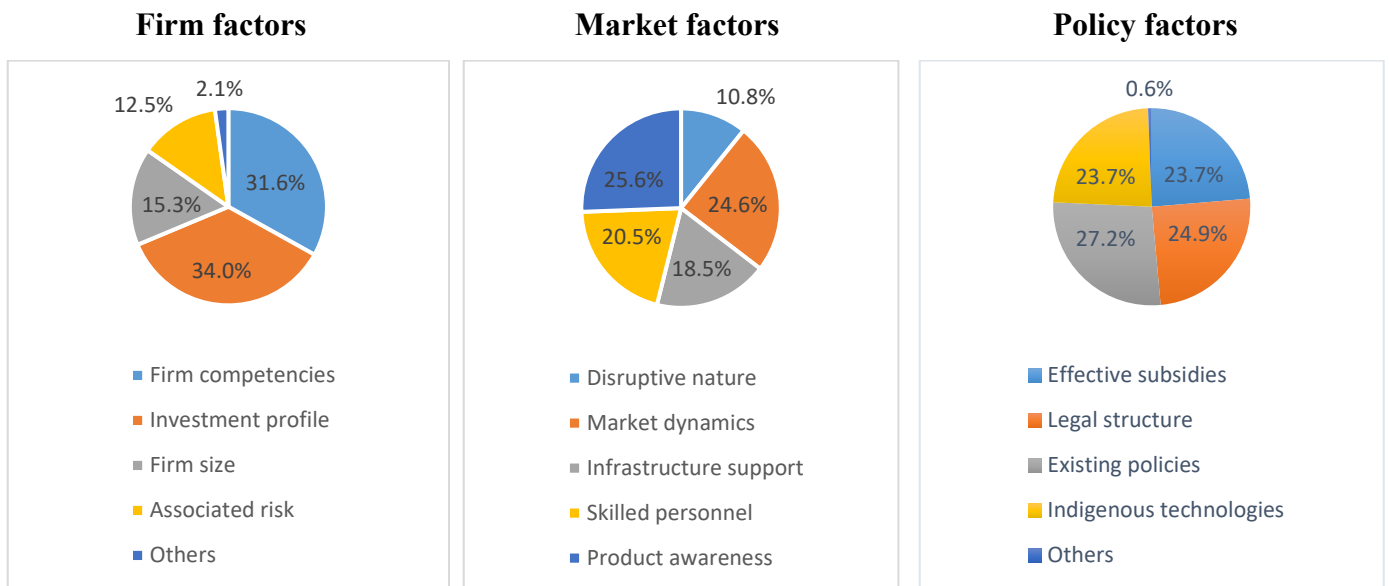
**Figure 4.10:** Institutional allocation of resources for commercialization

Institutional innovation and commercialization require significant resources to promote economic growth, job creation, technological transfer, and cooperation, address social concerns, generate income, and enhance institutional reputation. By fostering an innovative culture and encouraging entrepreneurship, these efforts contribute to society's general prosperity and advancement. Most participating R&I institutions, except for certain universities (52%), research institutes (42%), and private enterprises (25%), reported committing resources to support commercialization efforts

(Figure 4.10). These institutions primarily consisted of private and research organizations that aimed to generate revenue through education and training by committing resources to support commercialization efforts.

#### 4.3.5 Innovation Commercialization Outcomes

Firms often face significant challenges when converting their R&D into profitable products. To address this, the study proposes an intervention framework integrating policy, firm, and market-level interventions to bridge CVD and bring new technologies to the market (Figure 4.11). This framework acknowledges the interconnectedness of policy, firm strategies, and market dynamics in overcoming the hurdles of innovation commercialization. Although extensive research exists on CVD, there is a lack of comprehensive analysis of the intricate relationships between firm-specific capabilities, market dynamics, and regulatory frameworks in developing countries such as Uganda. The results indicate that a robust R&D infrastructure and supportive government regulations are crucial factors.



**Figure 4.11:** Firm, market, and policy factors influencing CVD among techno-business actors

However, market-related elements such as public awareness and the adoption rate of new technologies have substantially influenced their effects. This demonstrates a complex network of interconnected factors that have not been thoroughly examined in previous studies. This study contributes to the theoretical knowledge base by elucidating the complex factors influencing CVD in developing countries and providing practical recommendations for policymakers. It proposes a

multifaceted approach to enhancing innovation ecosystems, encompassing targeted support for R&D infrastructure, initiatives to facilitate market access, and modifications to regulatory frameworks.

A unique value proposition is crucial for a product's success; this proposition can enhance efficiency, productivity, and performance, thereby providing users with additional benefits. According to this study, 34% of firms identified investment-related challenges and value propositions as firm-specific factors affecting innovation commercialization in Uganda (Figure 4.11). According to research, a product with advanced technology may not always perform better than a product with less technology, but with effective management and marketing. Uganda has a long history of business practices and is known for its uniquely crafted products (Fashina et al., 2018; World Bank, 2021). Our findings suggest that individuals with strong technical skills and experience in Uganda's knowledge-based economy oversee startups and techno-business firms.

The need for technological advancement in Uganda is primarily driven by social issues. According to the survey, 25.6% of firms view public awareness and product acceptability as crucial market-driven factors affecting innovation commercialization in Uganda (Figure 4.11). Addressing the high cost of adoption is essential for overcoming barriers to innovation development and adoption. Several researchers have argued that a product's value in the eyes of customers determines its price (Crowley & McCann, 2018; Kim et al., 2019; Avenyo et al., 2021). To justify the higher prices of advanced technology, it is essential to emphasize its benefits, which outweigh the increased costs incurred by the users. Ugandan society's focus on enhancing social conditions and well-being makes it crucial to raise public awareness and embrace innovation for successful commercialization.

A well-balanced regulatory framework and government assistance program are essential for promoting innovation adoption. The study results indicate that 27.2% of the firms identified a stable innovation and commercialization policy environment as a key factor affecting innovation commercialization (Figure 4.11). Although Uganda has made notable progress in becoming a significant market player through effective policies and processes that foster growth, concerns have been raised regarding the lack of a comprehensive and consistent policy approach. Appropriate government policies are crucial for creating favourable conditions that drive

technological advancement. The existing national innovation ecosystem in developing countries, such as Uganda, lacks linkages and interrelationships between various actors, and the connection between knowledge creators and users is inadequate. To bridge this gap, researchers, innovators, and techno-business firms must go beyond generating useful knowledge and ideas. Instead, they must consciously work together to establish mechanisms that promote innovation commercialization, inspire active involvement in designing marketable products, and assume leadership roles to ensure successful commercialization.

Paper VI discusses the effects of CVD on the technopreneurship endeavours of researchers, innovators, and techno-business firms in Uganda. The findings reveal that market dynamics, robust R&D infrastructure, and supportive government regulations are among the crucial determinants of CVD (Table 4.6), offering new perspectives on bridging CVD in Uganda. A firm's success depends on its knowledge and expertise (Atiase et al., 2020; Kesselring et al., 2023). In this study, 12.1% of the surveyed firms identified knowledge, competencies, and expertise as determinants of CVD (Table 4.6). Management and marketing expertise are often overlooked in favour of technical professionals who prioritize technological advancements over effective communication with target clients. Firms with diverse backgrounds and expertise are better equipped to address this challenge and develop solutions to real problems.

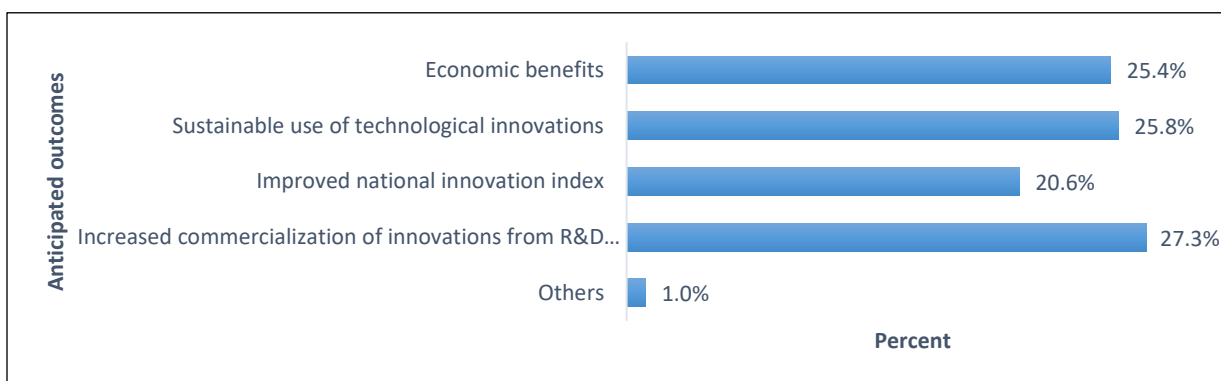
**Table 4.6:** *Determinants of CVD among researchers, innovators, and techno-business firms*

<b>Determinants of commercialization valley of death (CVD)</b>	<b>Percent (%)</b>
Knowledge, competencies, and expertise	12.1
Value proposition and investment profile	11.4
Policy environment	9.1
Product acceptance and awareness	8.6
Existing legal structure	8.4
Market size and related issues	8.3
Enterprise support schemes	8.0
Techno-based indigenous technologies	8.0
Availability of skilled personnel	6.9
Infrastructure support	6.2
Enterprise size and collaborative nature	5.1
Risk at the enterprise level	4.2
Disruptive nature of the enterprise	3.6
Others	0.1

The intervention framework in Figure 4.3 (Page 61) is a direct response to the determinants of CVD identified in Table 4.6 (Page 70), in order to address the top-ranked determinant, ‘knowledge, competencies, and expertise’ (12.1%), the framework proposes firm-level interventions like ‘providing expert opinion and guidance.’ To tackle ‘policy environment’ (9.1%), it recommends policy-level interventions such as ‘enacting long-term policies’ and ‘eliminating bureaucracies.’ This direct mapping ensures that the framework is targeted and evidence based. By simultaneously overcoming multilevel barriers, businesses can better navigate CVD and innovate their products. The proposed interventions create a supportive innovation ecosystem, foster stakeholder collaboration, and provide the necessary resources for firms to make their R&D commercially viable.

#### 4.3.5 Long-Term Innovation Commercialization Impacts

Innovation commercialization experts highlighted the following indicators for evaluating success or progress at the firm, market, and policy levels, in line with the commercialization framework (Figure 4.12). Eliminating commercialization obstacles can result in beneficial outcomes such as increased market acceptability, enhanced competitive advantage, broader market reach, and contributions to economic growth and societal well-being. By doing so, firms can gain favourable market influence, establish strong market positions, and foster long-term growth in their ideas. This study highlights that startups, spinoffs, and techno-business firms must acquire essential knowledge, skills, and resources to commercialize technological innovations.



**Figure 4.12:** Anticipated outcomes of overcoming firm-specific, market-centric, and policy-related barriers to commercialization of innovations

Suitable infrastructure is crucial, and firms can use facility parks, incubation facilities, and professional associations to compensate for their limited resources. Securing funding is an

essential aspect of the development process, and firms can attract investor interest by acquiring technical skills and developing well-defined commercialization plans. By integrating strategies and measures at the firm, market, and policy levels, the framework highlights the necessity of collaboration among stakeholders to promote public understanding and recognize the economic benefits of technology commercialization. The developed commercialization framework necessitates a comprehensive approach that considers the country's unique technological regimes, firm sizes, and socioeconomic conditions. Strategies should be customized to effectively manage the innovation process, ranging from financing and development to diffusion and legitimation, with a focus on overcoming socioeconomic barriers and optimizing business models in the local context.

#### **4.4 Exploratory Factor Analysis (EFA) Results**

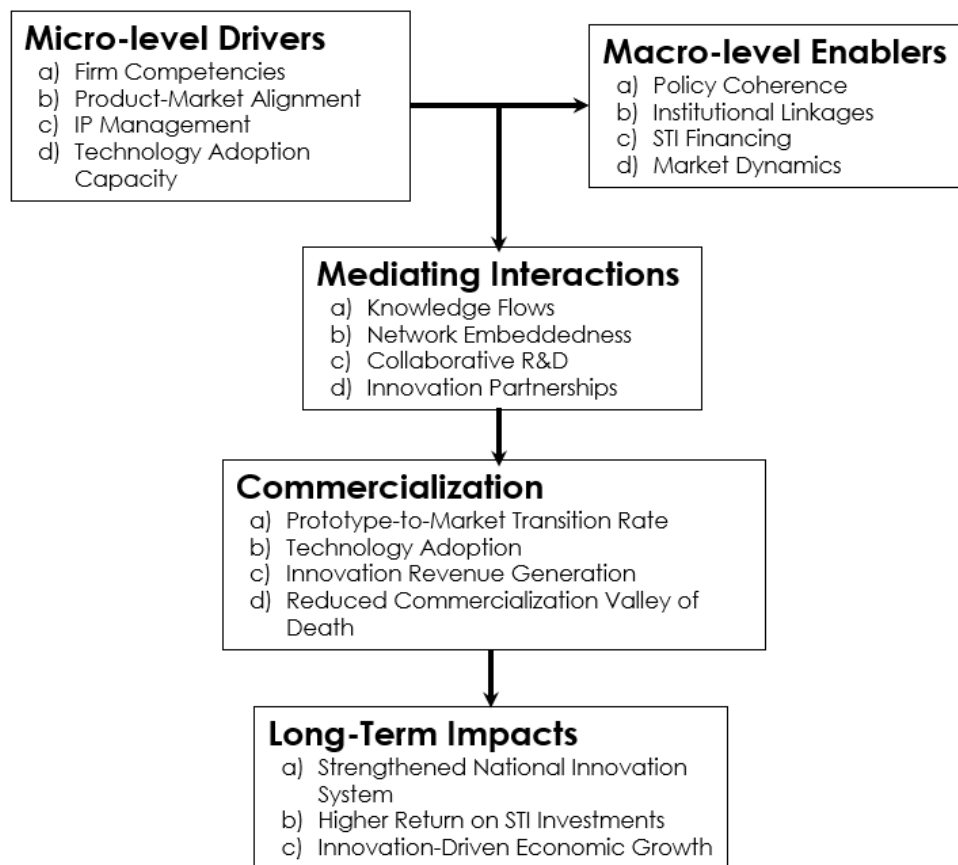
Based on the qualitative and quantitative results, Exploratory Factor Analysis (EFA) was conducted to refine constructs and identify underlying factor structures for the micro-level, macro-level, mediating, and outcome variables. The EFA revealed distinct, interpretable factors corresponding to the conceptual framework: Firm-Level Competencies, Product–Market Alignment, Innovation Policy Coherence, Institutional Linkages, STI Financing, IP Management Capacity, and Innovation Commercialization Performance. This technique supports the development of a robust, evidence-based framework by revealing latent structures within qualitative and quantitative data, thereby enhancing construct validity and guiding targeted interventions. In the context of Uganda’s innovation ecosystem, the EFA provides empirical rigor to the integrative commercialization framework, enabling stakeholders to focus on key drivers and barriers at the micro and macro levels and facilitating a systematic approach to bridging the commercialization valley of death. All factor loadings exceeded the acceptable thresholds, and items with cross-loadings were removed.

#### **4.5 Validated Integrative Commercialization Framework**

Based on the qualitative themes, and Exploratory Factor Analysis (EFA) outputs, the study developed a validated Integrative Commercialization Framework (Figure 4.13) consisting of:

- a) *Micro-Level Drivers*: These included firm competencies, product–market alignment, IP management, and technology adoption capacity.

- b) *Macro-Level Enablers*: These include policy coherence, institutional linkages, STI financing, and market dynamics.
- c) *Mediating Interactions*: These include knowledge flows, network embeddedness, collaborative R&D, and innovation partnerships.
- d) *Commercialization Outcomes*: These include prototype-to-market transition rate, technology adoption, innovation revenue generation, and reduced commercialization valley of death.
- e) *Long-term Impacts*: These include a strengthened national innovation system, higher returns on STI investments, and innovation-driven economic growth.



**Figure 4.13:** Validated integrative commercialization framework

The framework provides structured pathways for improving commercialization performance across Uganda’s innovation ecosystem, which are further synthesized to develop a comprehensive

model framework integrating strategies and measures for innovation commercialization at the firm, market, and policy levels.

#### 4.6 A Comprehensive Model Framework Integrating Strategies and Measures for Innovation Commercialization at the Firm, Market, and Policy Levels

The comprehensive framework presented in Figure 4.14 synthesizes all our findings into a dynamic model for guiding technological innovation from conception to the market in Uganda. It moves beyond a linear process to illustrate a system where:

- Firm-level capabilities (the engine) drive innovation development.
- These firm-level capabilities are either constrained or enabled by the market/economic (demand, competition) and policy/regulatory (laws, funding) contexts.
- Successful commercialization is not an endpoint but a cycle in which market feedback and policy learning inform future R&D and firm strategy, fostering a sustainable innovation ecosystem.
- This framework provides a holistic map for stakeholders to identify leverage points and potential bottlenecks in the entire ecosystem.

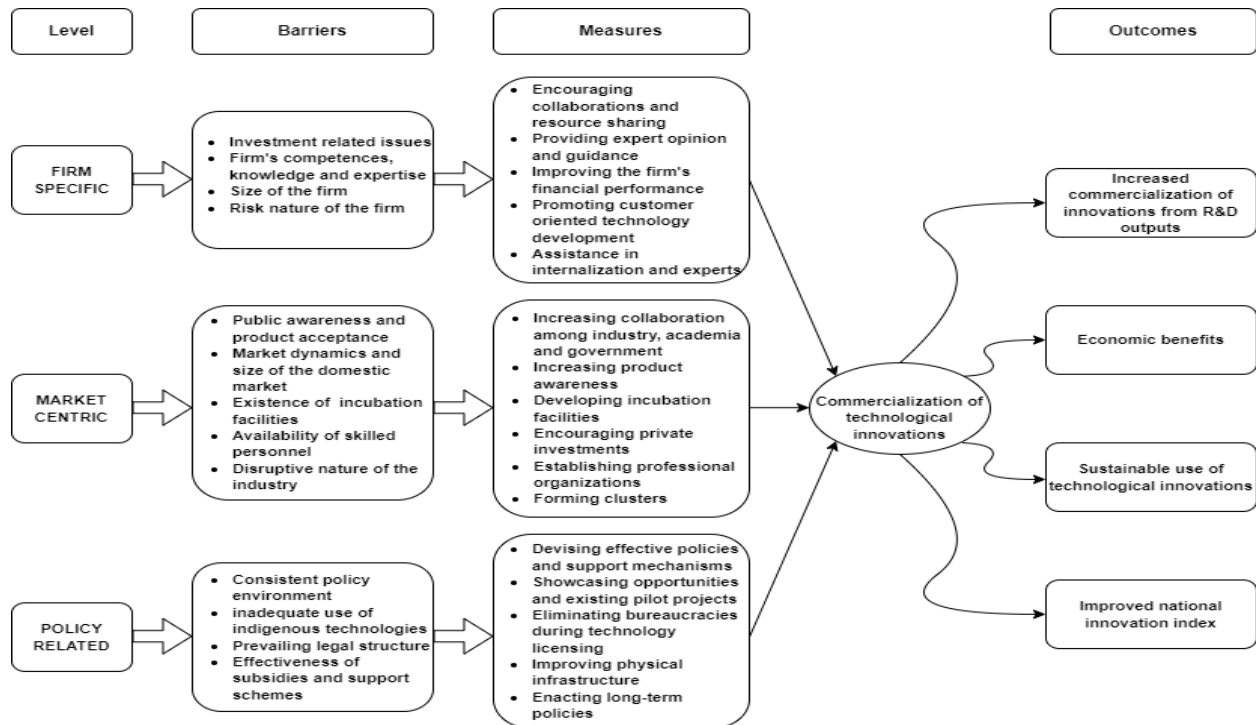


Figure 4.14: A Model Framework for Commercialization of Technological Innovations

While this framework focusses on the core economic and commercial pathways, its practical application must be complemented with considerations of social equity and environmental sustainability to achieve truly inclusive and sustainable development. This represents a critical area for future research. A multifaceted approach is needed to effectively bridge CVD, including the effective management of innovation through Technology Transfer Offices (TTOs), providing technopreneurship education in universities, and developing business models that facilitate the commercialization of new technologies. Furthermore, creating an ecosystem that supports innovation commercialization can help nurture technopreneurship. Thus, a collaborative effort between educational institutions, industry, and policymakers is crucial to successfully transition from research to market and support the growth of techno-business firms.

## CHAPTER FIVE: DISCUSSION

### 5.1 Introduction

This chapter interprets the findings presented in Chapter Four in relation to existing literature, theoretical foundations, and the research objectives. The discussion highlights how the study advances understanding of innovation commercialization in Uganda and contributes to global knowledge on commercialization frameworks for developing-country contexts. The findings of this study reveal that the failure to commercialize innovations in Uganda is not due to isolated issues but is a symptom of a disconnected ecosystem. This discussion demonstrates how fragmented actor linkages, misaligned R&D funding, and uncoordinated barriers collectively create the CVD and how the proposed framework is designed to reintegrate this system.

### 5.2 Discussion of Qualitative Findings

#### 5.2.1 *Fragmented Innovation Ecosystem*

The qualitative findings reveal a highly fragmented innovation ecosystem characterized by weak coordination among firms, universities, research institutions, and government agencies. This is consistent with the literature on developing economies, where institutional silos frequently hinder commercialization (Refs). The absence of shared platforms and coordinated STI structures limits knowledge transfer and reduces the efficiency of commercialization.

Existing NIS frameworks predominantly focus on innovation processes in advanced economies. Consequently, they often fail to adequately address the specific challenges and opportunities faced by developing nations such as Uganda. These countries contend with unique issues, including inadequate infrastructure, diverse socioeconomic landscapes, and disparate levels of technology adoption, which are not sufficiently captured in the current NIS models. This study challenges the presumption of pre-existing functional institutions in the mainstream NIS literature. In contexts such as Uganda, the NIS is not a platform for interaction but a field of action where building linkages is a primary innovation challenge. Our modified framework (Figure 1.1) thus contributes a constructionist view of the NIS in developing economies. According to Kurpayanidi (2023) and Wen (2023), understanding the NIS is critical for optimizing a country's innovation capabilities to achieve sustainable development. The stability and adaptability of an NIS are particularly vital, as they determine its capacity to remain balanced and responsive to change, which is essential for continuous innovation, as highlighted by Noeh et al. (2023).

While the NIS framework has been adopted in various countries, there are notable differences in its conceptualization and effectiveness between developed and developing countries (Fernandes et al., 2022). For example, small countries such as Brunei have shown that possessing an appropriately designed NIS can support economic advancement through capacity building and digitalization (Noeh et al., 2022). Conversely, in China, the concentration of the NIS within large state-owned enterprises has been diverted from promoting sustainable innovation in SMEs (Jia et al., 2020). This demonstrates that the structure and focus of the NIS can significantly influence its transformative and resilient capabilities.

The NIS holds considerable theoretical significance for Uganda in achieving sustainable development, transformation, and resilience. Research suggests that a well-structured NIS can foster economic growth by promoting innovation and adaptability (Fernandes et al., 2022; Noeh et al., 2023). However, the effectiveness of such a system depends greatly on how it is conceived and implemented, particularly regarding inclusivity and support for SMEs (Jia et al., 2020; Abate & Sheferaw, 2023). Therefore, adopting a strategic and inclusive approach to the NIS in Uganda is essential for realizing its sustainable development goals.

Future iterations of Uganda's NIS should actively engage and support grassroots innovators, recognizing their critical role in fostering resilience and promoting sustainable growth (Okumu & Buyinza, 2020; Salmon et al., 2020). This support may include establishing dedicated funding mechanisms, mentorship programmes, and innovation hubs tailored to meet the specific needs of these groups. The NIS framework in Uganda can also be enhanced by developing sector-specific innovation strategies tailored to address challenges and capitalize on opportunities in key sectors such as agriculture, healthcare, and renewable energy (Mulumba et al., 2017; Fashina et al., 2018). Such a targeted approach would improve the relevance and effectiveness of innovation efforts in line with the national development priorities.

To further improve the effectiveness of Uganda's NIS, it is imperative to strategically align it with the nation's educational policies. This alignment should prioritize the advancement of STEM education and vocational training programs that equip the workforce with the requisite skills for innovation-led economic growth (Okwakol et al., 2022). Moreover, Uganda's NIS can be significantly strengthened through the implementation of digital transformation strategies. These

may include initiatives to enhance digital literacy, foster digital entrepreneurship, and invest in the development of digital infrastructure (Bowman, 2019; Pius & Owin, 2024), all of which would contribute to a more robust innovation ecosystem.

The government and policymakers must ensure the effective implementation of STI policies that foster interaction and learning among NIS actors in Uganda. Integrating resilience and sustainability within social-ecological systems further emphasizes the need for social transformation and behavioural change in addressing development challenges (Aktar et al., 2021; Okwakol et al., 2022). Although innovation systems are pivotal to global sustainable futures, research on the linkages between NIS and sustainable development remains limited, particularly at the national level (Fernandes et al., 2022). This gap highlights a crucial opportunity for Uganda to develop an NIS that actively supports sustainable development through systemic change and sustainable consumption behaviours (Mulumba et al., 2017; Bowman, 2019).

Transforming the NIS in transitioning economies such as Uganda underscores the importance of human capital and institutional entrepreneurship in stimulating institutional change (Okwakol et al., 2022). This insight is relevant to Uganda's efforts to develop a dynamic and responsive innovation system. In summary, the policy recommendations for Uganda's NIS should focus on the following aspects:

- a) Developing a robust communication strategy to bridge information gaps and raise public awareness;
- b) Promoting behavioral changes to address environmental challenges;
- c) Strengthening the NIS to support sustainable development;
- d) Leveraging institutional entrepreneurship to drive transformation.

These actions should align with Uganda's broader goal of achieving Sustainable Development Goals (SDGs) (NPA, 2019; United Nations, 2020). While this study emphasizes the critical role of STEM education in driving innovation, it does not provide a thorough analysis of how current STEM policies enhance innovation capabilities among Ugandan youth. Therefore, future policy initiatives should aim to develop a comprehensive digital transformation strategy that includes investments in digital infrastructure, programs to boost digital literacy, and incentives for digital entrepreneurship (Okwakol et al., 2022).

To address the fragmented nature of Uganda’s NIS, there is a need to establish a National Innovation Council that brings together stakeholders across key sectors to coordinate efforts and share best practices. Future innovation policies should integrate sustainability principles to ensure that innovation meaningfully contributes to Uganda’s development agenda. Importantly, these policies must enhance inclusivity within the innovation ecosystem, ensuring that women, rural populations, and other underrepresented groups are actively involved in multi-level innovation processes (Nahikiriza, 2023). Thus, a fragmented NIS undermines the collaborations needed for it to be effective. This systemic weakness is further exacerbated by the allocation and management of R&D funding, as discussed in Section 5.2.2.

### ***5.2.2 Insufficient STI Financing and Funding Mechanisms***

Participants highlighted a lack of low-interest innovation financing, venture capital, and government-funded commercialization schemes. This mirrors findings in literature that early-stage financing is the most critical barrier to crossing the “commercialization valley of death” (Markham, 2013). Without adequate funding, prototypes rarely progress to market-ready products.

Research and development (R&D) funding and technological innovation are positively correlated, whereas financial structure and support are significantly related to scientific and technological innovation (Hogan et al., 2022; Kurekova et al., 2023). Government R&D investment has been shown to enhance scientific and technological performance, although its effect on commercialization is not evident (Pisár et al., 2020). A combination of different funding sources, including R&D grants, can positively affect innovation outcomes (Acebo and Miguel-Dávila, 2024). However, the efficiency of financial organizations and environmental regulations can have varying impacts on the commercialization of R&D innovation (W. Chen et al., 2023). The literature indicates that government grants do not crowd out private funding but stimulate private R&D expenditure, with private financing positively influencing innovation (Kurekova et al., 2023; Acebo and Miguel-Dávila, 2024). Additionally, the relationship between R&D grants and innovation is nuanced and influenced by factors such as firm lobbying, industry competition, and geographic dispersion (Unsal and Houston, 2024).

R&D funding positively correlates with R&D outcomes in sustainable development; however, disparities exist among states (Kurekova et al., 2023). Subsidiary R&D support through grants and tax credits can lead to significant firm performance payoffs in the host economy (Lenihan et al.,

2023). The innovation spirit of SMEs significantly promotes innovation performance, with R&D investment serving as an internal transmission mechanism (Yin et al., 2023). Public support for R&D positively affects private investment in business R&D in the EU (Pisár et al., 2020). Therefore, the theoretical implications drawn from the literature suggest that R&D grants and investments can contribute positively to innovation commercialization. This is contingent on a supportive financial structure, a combination of various funding sources, and the influence of environmental and firm-specific factors.

The government of Uganda, through the UNCST, must maintain momentum in gathering STI indicators to support the evidence-based formulation of effective STI policies. Furthermore, the UNCST should collaborate with its partners to regularly report standard STI indicators required to inform national STI discourse. The effectiveness of R&D grants in stimulating innovation is evident, as they significantly impact the innovation process (Acebo & Miguel-Dávila, 2024). In addition, government R&D funding has been shown to enhance scientific and technological performance (Lenihan et al., 2023). However, the commercialization of government-funded R&D is not guaranteed, as indicated by the lack of government R&D funding for commercialization (Yin et al., 2023). This suggests that while R&D grants are crucial for innovation, additional mechanisms may be required to translate these innovations into marketable products and services. Fiscal incentives, including tax policies, have been highlighted as complementary measures for facilitating investment in R&D and innovation (Zhang et al., 2023).

Moreover, it emphasizes the importance of considering the characteristics of the technology sector and regional characteristics when allocating government R&D funding (Yinet al., 2023; Zhang et al., 2023). This is particularly relevant in Uganda where regional disparities and sector-specific challenges may exist. Policies should not only provide R&D grants but also ensure that these grants are part of a broader policy mix that includes fiscal incentives and considers the specificities of various sectors and regions. Additionally, mechanisms to support the commercialization of innovations should be integrated into the R&D funding framework to maximize the economic impact of such investments. The findings from the literature underscore the need for a nuanced approach to R&D funding beyond the provision of grants to include supportive measures for commercialization (Yin et al., 2023; Zhang et al., 2023; Acebo and Miguel-Dávila, 2024).

### ***5.2.3 Limited Firm-Level Commercialization Capacities***

Respondents reported inadequate expertise in product development, market research, and IP management. This aligns with the Resource-Based View (RBV), which emphasizes that firm capabilities directly influence innovation outcomes (Lages et al., 2023). The findings underscore the need for capacity-building interventions targeted at SMEs and innovation-active firms.

To successfully apply strategies to improve innovation and commercialization in techno-business firms in Uganda, it is essential to consider the results and outcomes of various studies focusing on innovation, commercialization, and business performance. Techno-business firms must prioritize the development of efficient business models that facilitate the commercialization of innovative products, as this can greatly enhance their economic potential and value delivery (Kusumawati et al., 2022). Furthermore, implementing agile methods can improve the effectiveness of innovation processes, resulting in prompt and successful commercialization of new technologies (Lages et al., 2023). In addition, corporations must formulate innovation strategies that encompass products, processes, markets, and technological innovation, as studies have shown that these factors positively influence firm performance (Kanyi & Kihara, 2022).

Moreover, devising technological catch-up strategies and government support programs may enhance a firm's capacity for innovation in new product development, which is essential for businesses to remain competitive and meet market expectations (Mukhtar et al., 2021). Additionally, technology-driven business analytics can assist techno-business firms in making well-informed decisions that promote growth and provide a competitive advantage (Kumar & Aithal, 2024). Adopting ambidextrous innovation, which entails reconciling market-driven business models, may result in improved organizational performance (Kusumawati et al., 2022). Market orientation and innovation have been shown to have a positive relationship with business performance, and it is essential to consider the regulatory influence of the business environment when devising strategies (Giang, 2022).

Techno-business enterprises must also adapt to the evolving marketing landscape, particularly the emergence of web-based marketing tactics (Mogull, 2021). Comprehending monetization processes in Internet marketing can assist organizations in transforming target audience behavior into revenue streams, which is crucial for small businesses (Mishra et al., 2024). Uganda's techno-

business enterprises should develop tailored business models, implement agile and innovative strategies, capitalize on government support for new product development, leverage business analytics, balance business model ambidexterity, maintain market orientation, adapt to evolving marketing strategies, and comprehend Internet marketing monetization processes to enhance innovation and commercialization. These strategies are underpinned by empirical evidence demonstrating their positive impact on firm performance and commercialization (Kanyi & Kihara, 2022; Kusumawati et al., 2022; Lages et al., 2023; Kumar & Aithal, 2024).

#### ***5.2.4 Challenges in Achieving Market Readiness***

Challenges in achieving market readiness in Uganda's innovation ecosystem include inadequate institutional support, limited market validation, and difficulties in meeting certification and standard requirements. Innovations often stall beyond the pilot or prototype stages due to insufficient user engagement and the absence of structured commercialization pathways. Techno-business firms face obstacles such as weak market analysis skills, poor product testing capabilities, and low public awareness of new technologies, which constrain their ability to position products effectively and gain consumer acceptance. The fragmented innovation ecosystem further exacerbates these challenges by limiting coordinated efforts for market entry and scale-up (Shmeleva et al., 2021; Kreiterling, 2023). Additionally, the lack of private sector collaboration and insufficient financial mechanisms hinder firms' capacity to navigate market dynamics and regulatory environments, delaying the transition from development to commercialization. These factors collectively underscore the need for comprehensive interventions to enhance market readiness through improved infrastructure, capacity building, and strengthened institutional linkages.

To comprehend the difficulties that techno-business companies in Uganda face with innovation and commercialization, it is crucial to consider the broader context of startup ecosystems in emerging markets and the challenges that technology-focused startups encounter. Although the resources provided do not specifically refer to the Ugandan context, they offer useful information regarding common obstacles that can be applied to the Ugandan situation. Techno-business firms especially those in the technology sector, often grapple with a lack of institutional support, which can impede their growth and hinder their ability to innovate (Bakhtiar et al., 2020; Maulana et al., 2022). Moreover, the rapid pace of technological change, unpredictable customer demand, and

market profitability are crucial market contingencies that startups must navigate (Butnik-Siverskyi et al., 2024). These challenges are further compounded by the need for startups to collaborate with innovation ecosystems to support their technological and business model innovations, which may be underdeveloped in emerging markets such as Uganda.

Startup techno-business firms frequently face obstacles when attempting to monetize innovations, particularly when counting external entities within their innovation ecosystems to navigate market uncertainties (Butnik-Siverskyi et al., 2024). In addition to establishing strategic alliances, techno-business enterprises must comprehend regulatory and ethical concerns and consistently adjust to technological advancements and market shifts to achieve success (Maulana et al., 2022). Techno-business enterprises in Uganda are likely to face challenges similar to those encountered in other emerging markets, including inadequate institutional support, the complexity of navigating rapidly changing technological environments, and the need for developed innovation ecosystems. To overcome these obstacles, strategic planning, the development of innovation ecosystems, and a thorough understanding of the local context are necessary to facilitate the commercialization of technology and the sustainable growth of startups (Maulana et al., 2022; Butnik-Siverskyi et al., 2024; Pererva et al., 2024).

### ***5.2.5 Weak Policy Coherence and Implementation Gaps***

The results show that Uganda's STI policies lack synergy and predictable implementation. The literature indicates that policy fragmentation reduces confidence among innovators and undermines national innovation system performance (OECD, 2021; Zhang et al., 2023). This reinforces the need for harmonized policies to support commercialization. While the Triple Helix model emphasizes the role of university-industry-government collaborations in fostering innovation ecosystems (Zhuang et al., 2021; Noya & Taneo, 2023), the findings of this study on the fragmentation of the R&I ecosystem in Uganda and inadequate support infrastructure highlight a critical gap in the model's applicability to developing countries. The study findings necessitate a critique of the Triple Helix model in developing contexts. We observed not only a weak helix but also disconnected strands. This suggests the need for a 'Fourth Helix' – a dedicated, independent intermediary or system integrator to actively weave the other three together. This is the role that our framework implicitly assigns to coordinated policies and support institutions.

Specifically, the study reveals a disconnection between policy intentions and on-the-ground realities, suggesting that the Triple Helix model may require adjustments to accurately reflect the challenges faced in these contexts in the future. Moreover, findings on financial barriers, including reliance on external funding and the lack of a national research fund, point to a significant gap in the literature on financing innovation in developing countries (Salmon et al., 2020; Moon, 2022). This study contributes to the theoretical understanding by illustrating the complexities and challenges of securing sustainable financing for innovation in environments where government support may be inconsistent and external funding sources dominate. These insights could inform the development of new theoretical frameworks or the refinement of existing models to better account for the financial realities of innovation commercialization in similar settings. There is no formal mechanism for funding long-term research and innovation because of the government's shifting priorities and the absence of an approved framework for innovation and research funding.

Tweheyo et al. (2024) indicate that institutional elements play a crucial role in university commercialization processes, emphasizing patent policies, revenue distribution systems, and entrepreneurial education for researchers. This perspective aligns with the work of Min et al. (2020), which emphasizes the significance of TTOs in enhancing commercialization success rates at research universities through appropriate organizational structures and entrepreneurial initiatives. Namugenyi et al. (2023) presents an alternative viewpoint by examining the potential adverse effects of innovation, specifically how implementing biomass technology innovations may lead to the erosion of traditional cooking practices, thereby affecting the subjective well-being of households. This insight underscores the necessity of considering socio-cultural contexts in the commercialization process, as innovations may have unanticipated consequences for societal norms and customs. The conceptual implications suggest that the practical commercialization of innovations within Uganda's research and innovation sector necessitates a comprehensive strategy. Critical factors contributing to success include institutional elements such as conducive policies and frameworks, entrepreneurship education, and the role of TTOs (Tweheyo et al., 2024). Furthermore, it is imperative to assess the societal and cultural implications of innovation, as these factors can influence public acceptance and well-being (Namugenyi et al., 2023). These findings enhance our understanding of the commercialization process and identify areas for further investigation and policy development (Namugenyi et al., 2023; Tweheyo et al., 2024).

Policies must address knowledge gaps in understanding the specific regulatory barriers that most significantly impede commercialization, such as stringent intellectual property laws that deter innovation rather than encourage it. There is a critical knowledge gap in identifying which R&D infrastructural elements significantly enhance commercialization outcomes, necessitating targeted studies to inform infrastructure development policies (Nahikiriza, 2023; Pius & Owin, 2024). Policies must be informed by a deeper understanding of the factors that motivate or deter private sector investment in R&I, particularly in developing countries, such as Uganda, where economic conditions differ significantly from those in developed economies. A significant knowledge gap exists in identifying effective and sustainable financing models for innovation that combine government funding, private investment, and international partnerships (Salmon et al., 2020; Sendawula et al., 2023). Future policies should be informed by research on successful models in similar economies. Empirical research is needed to determine the most effective mechanisms for implementing innovation policies in Uganda, including stakeholder engagement strategies, policy communication, and the role of intermediaries in bridging the gap between policymakers and R&I institutions. Policymakers and stakeholders must strengthen the legal and regulatory framework for innovation, intellectual property protection, and commercialization, and ensure the effective enforcement of existing restrictions to enhance the R&I ecosystem in Uganda.

Tweheyo et al. (2024) emphasize the importance of institutional factors, including patent policies, revenue-sharing frameworks, and the necessity of developing entrepreneurial skills among researchers. These elements play a crucial role in enhancing the commercialization of university research outputs. Similarly, Onapa et al. (2020) and Nahikiriza (2023) highlighted the significance of well-coordinated STI policies among various stakeholders. They suggest that political commitment and initiatives such as the MSI can foster innovation. However, challenges have been identified, including the absence of a cohesive system for STI policy coordination and the underdeveloped state of technological advancement and commercialization within academic institutions.

Namugenyi et al. (2023) elucidated the unanticipated negative consequences of biomass technology innovation on the perceived well-being of Ugandan households. This finding underscores the significance of policymakers considering both the advantages of bioenergy advancements and the welfare of those utilizing the technology. This further emphasizes the

necessity of policies that achieve an equilibrium between technological progress and sociocultural values. For efficient innovation commercialization in Uganda, policymakers should prioritize establishing supportive institutional structures, enhancing researchers' entrepreneurial capabilities, and ensuring well-coordinated STI policies (Onapa et al., 2020; Tweheyo et al., 2024). Moreover, policies should foster an environment that facilitates collaboration between the public and private sectors, while addressing the specific requirements and challenges encountered by research and innovation institutions within the country.

### ***5.2.6 Need for a Nationally Integrated Commercialization Framework***

The model framework developed in Figure 4.14 (Page 75) offers three key theoretical advancements. First, it is explicitly multilevel, integrating firm capabilities, market dynamics, and policy levers into a single feedback loop, moving beyond predetermined interventions. Second, it is context-specific, designed around the identified determinants of CVD in Uganda (Table 4.6), such as low product awareness and unstable policies. Third, it is action-oriented, translating systemic diagnosis into discrete interventions at the policy, firm, and market levels, as shown in Figure 4.11 (Page 69). This represents a significant departure from generic linear commercialization models.

Commercializing innovation is unlikely to be effectively achieved through a one-size-fits-all approach because factors such as firm size and technological regimes are critical considerations (Min et al., 2020; Loganathan & Subrahmanya, 2022). The inherent challenges of science commercialization, such as uncertainty and high capital requirements, underscore the need for customized strategies and frameworks that can generate economic and social value (Bakhtiar et al., 2020). A review of technology financing and commercialization processes, including the importance of bridging the gap to mass markets (“crossing the chasm”), and the necessity of understanding customer segments and the national innovation system for successful commercialization (Gong et al., 2021). The high-risk and high-cost nature of commercialization, particularly in high-tech markets, further highlights the need for strategic management and the significant influence of commercialization decisions on market success or failure (Kruachottikul et al., 2023).

The slow pace of technological advancement in Organisation for Economic Cooperation and Development (OECD) countries, attributed to social and economic challenges (OECD, 2021),

suggests that similar barriers may exist in Uganda. Therefore, promoting the adoption and diffusion of innovation requires addressing both supply- and demand-side factors (Mallinson, 2021). Business models play a vital role in facilitating the adoption and spread of new technologies. Innovation providers must adapt and refine these models to effectively connect with end users (Noeh et al., 2022a). The role of e-business entrepreneurs in advancing cloud computing adoption, as demonstrated by social cognitive theory, highlights the importance of social learning and individual belief systems in influencing technology adoption (Chen, 2024). Additionally, the innovation legitimation process, which serves as an essential step towards the broader adoption of groundbreaking innovations, underscores the role of system builders and the need to align organizational visions within the broader innovation ecosystem (Yim et al., 2024).

In the Ugandan context, a comprehensive commercialization approach must consider the country's unique technological regimes, firm size, and socioeconomic conditions. Strategies should be customized to effectively manage the innovation process across all stages, from financing and development to diffusion and legitimacy. These strategies must also address socioeconomic barriers and promote the optimization of business models to suit local conditions. Understanding the role of system builders and the importance of aligning visions within the innovation system can further strengthen the commercialization of technological innovations in Uganda.

Policymakers and stakeholders must implement robust policies to enhance STI ecosystems. This includes improving legal and regulatory frameworks to support the commercialization of innovations (Min et al., 2020; Kruachottikul et al., 2023). This study highlights several gaps and obstacles within Uganda's STI ecosystem and proposes actionable strategies to address them. To address the systemic fragmentation identified in this study, the primary policy imperative is to establish a National Innovation Council. This body would not be another layer of bureaucracy but an operational integrator needed to execute the coordinated interventions outlined in our framework. Given that 27.2% of firms identified an unstable policy environment as a key barrier (Figure 4.9), policy interventions must prioritize regulatory predictability and long-term commitment over short-term, project-based funding. Such efforts will drive transformational development by boosting industrial productivity and fostering private sector engagement.

Research and development (R&D) is a cornerstone of technological innovation. However, findings from various industrial sectors emphasize that post-R&D phases such as technology transfer and diffusion are equally crucial for economic growth and must be supported through appropriate government policies (Mallinson, 2021). While this study and its resulting framework focus on overcoming the economic and commercial barriers to innovation, we acknowledge that sustainable development requires the integration of social equity and environmental stewardship. The introduced framework provides an essential commercial engine; future research must integrate these critical dimensions to build a fully sustainable innovation vehicle for Uganda.

The success of technology commercialization among SMEs is closely tied to factors such as government support, intellectual property protection, innovative capacity, and investment in external R&D (Chen, 2024; Kurekova et al., 2023). This underscores the government's role as a key enabler of commercialization through financial and policy interventions. To successfully commercialize technological innovations, Uganda must establish comprehensive policies to provide support throughout all phases of innovation, from R&D to post-R&D activities, while also considering the social and cultural dimensions of innovation. Therefore, targeted support for SMEs is crucial to their survival. Ultimately, policymakers must foster an environment that promotes technological advancement, respects cultural traditions, and encourages inclusive economic growth.

### **5.3 Discussion of Quantitative Findings**

#### ***5.3.1 Micro-Level Drivers***

The study results confirm that firm competencies and product–market alignment significantly influence commercialization performance. This aligns with empirical studies showing that innovation success depends on internal capabilities such as R&D strength, strategic orientation, and technology adoption capacity. The effectiveness of these capabilities determines how well firms can navigate the complex commercialization process, adapt to market demands, and sustain competitive advantage. Empirical findings from Uganda’s innovation ecosystem highlight that firms with robust micro-level competencies are better positioned to overcome barriers such as limited product development expertise and weak market intelligence, which are common challenges in resource-constrained settings (Fashina et al., 2018; Salmon et al., 2020). Moreover, micro-level drivers enable firms to align their innovations with market needs, develop unique value

propositions, and engage in collaborative agreements that enhance innovation outcomes. However, these firm-level capabilities alone are insufficient without complementary ecosystem support, underscoring the need for integrated strategies that link micro-level drivers with macro-level enablers to effectively bridge the CVD.

### ***5.3.2 Macro-Level Enablers***

Policy coherence, institutional linkages, and STI financing are strong predictors of commercialization outcomes. These findings validate the NIS and Triple Helix theories, which emphasize system-wide collaboration and supportive policy environments (Zhuang et al., 2021; Noeh et al., 2023). In Uganda's innovation ecosystem, macro-level factors significantly influence commercialization outcomes by providing the necessary infrastructure, regulatory clarity, and financial resources that firms require to scale-up innovations. They foster collaboration among key actors such as government agencies, research institutions, and private sector players, thereby reducing fragmentation and enhancing knowledge flows. Additionally, macro-level enablers help align national innovation policies with market demands, thereby creating an enabling environment that mitigates the risks associated with CVD. This understanding aligns with findings from Uganda's innovation ecosystem studies, which emphasize the interplay between firm capabilities and systemic support structures in overcoming commercialization barriers.

### ***5.3.3 Mediating Commercialization Effects***

The study establishes that macro–micro interactions significantly mediate commercialization outcomes. This supports emerging systems-innovation literature suggesting that neither firm capabilities nor policies alone are sufficient, effective commercialization requires integrated ecosystem linkages (Fernandes et al., 2022; Strielkowski et al., 2023). By bridging firm competencies with supportive institutional frameworks and market conditions, these mediators enhance firms' capacity to adapt innovations to market needs, secure funding, and effectively navigate regulatory environments. Empirical evidence from Uganda's innovation ecosystem underscores that without these mediating interactions, the positive impact of firm-level capabilities and macro-level enablers on commercialization performance remains limited. Thus, mediating the commercialization effects serves as an essential conduit that integrates diverse ecosystem components, reduces fragmentation, and enables coordinated efforts to overcome barriers such as CVD, fostering sustained innovation-driven economic growth.

### ***5.3.4 Overall Commercialization Model Implications***

The integrated model provides a holistic understanding of commercialization, showing that improving Uganda's innovation performance requires simultaneous strengthening of micro-level firm capabilities and macro-level ecosystem conditions. This multidimensional view advances current literature, which often treats commercialization as a linear process (Pererva et al., 2024; Shcherbachenko & Kotenko, 2022). The commercialization model implies that effective innovation commercialization in Uganda requires an integrated approach that simultaneously addresses micro-level firm competencies, macro-level systemic enablers, and mediating interactions linking these components. The model underscores that firm capabilities alone are insufficient; they must be complemented by supportive institutional frameworks and conducive market conditions to be effective. Mediating factors such as knowledge flows, network embeddedness, collaborative R&D, and innovation partnerships are critical for bridging gaps, reducing ecosystem fragmentation, and enabling coordinated efforts. Without these mediating commercialization effects, the positive impacts of firm-level strengths and macro-level policies on commercialization performance remain limited. Therefore, the model advocates for a holistic, multi-level strategy that fosters alignment and synergy across firms, markets, and policy environments to overcome barriers like the commercialization valley of death, ultimately promoting sustained innovation-driven economic growth within Uganda's innovation ecosystem.

## **5.4 Contribution of the Study**

### ***5.4.1 Theoretical Contribution***

The study introduces a structured, context-specific commercialization framework tailored to developing economies. The framework demonstrates how micro and macro interactions jointly shape commercialization outcomes. It moves beyond simply identifying barriers to proposing an integrated intervention framework, as highlighted in Figure 4.10 (Page 69), which shows how policy, firm, and market actions must be coordinated.

### ***5.4.2 Empirical Contribution***

This study validates the key determinants of commercialization performance and provides hard evidence of Uganda's innovation system deficiencies. It provides one of the first empirically grounded, multilevel innovation commercialization models for bridging CVD in a low-income African context.

### ***5.4.3 Practical Contribution***

This study offers actionable guidance on innovation commercialization to firms, policymakers, and universities. It supports STI decision-making and investment prioritization. The comprehensive framework (Figure 4.13) offers a systems view of commercialization, replacing the linear model with a multilevel dynamic framework that emphasizes feedback and learning.

The contribution is not merely theoretical, the developed framework is designed as a practical tool for policymakers, innovators, and investors. It provides a clear roadmap for diagnosing commercialization failures and implementing targeted strategies, thereby offering a tangible solution to a problem that has for long hindered Uganda's economic development.

### **5.5 Chapter Summary**

This chapter interprets the qualitative and quantitative findings and aligns them with the theoretical constructs. The findings collectively demonstrate that commercialization in Uganda is hindered by systemic gaps but can be significantly improved through coordinated interventions at both firm and ecosystem levels.

## CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Introduction

This chapter presents the conclusions drawn from the study and provides policy, managerial, and research recommendations for strengthening innovation commercialization in Uganda. This thesis demonstrates that Uganda's innovation commercialization gap is not a failure of ideas, but rather a failure of systemic integration. This study reveals a critical disconnection between NIS actors, R&D funding allocation, and the market realities faced by firms. The comprehensive framework developed herein is not merely a model but a blueprint for action, designed to bridge these disconnections and systematically dismantle the CVD. The following conclusions, drawn from the study's objectives, affirm that a coordinated, multi-level approach is not only beneficial but also essential for transforming Uganda's innovation potential into economic reality.

### 6.2 Conclusions

#### *6.2.1 Innovation Commercialization in Uganda is Systemically Constrained*

Commercialization challenges stem from fragmented institutional linkages, weak policy coherence, and inadequate financing mechanisms. The study concludes that the fragmented and uncoordinated nature of Uganda's NIS is the primary cause of its low transformative capacity. Resilience is not inherent but must be built through deliberate strategies that strengthen formal and informal linkages between all ecosystem actors, which is a core principle of the proposed framework.

#### *6.2.2 Firm-Level Capabilities Are Critical but not Sufficient to Facilitate Innovation Commercialization*

While firms require competencies in R&D, market analysis, and IP management, these must be complemented by supportive ecosystem enablers. While R&D investment is crucial, this study concludes that its positive effect on commercialization is contingent on strategic alignment with market needs and firm-level capabilities. Current funding mechanisms in Uganda often fail to bridge this gap, highlighting the need for integrated grants that combine research support with commercial development resources. Mechanisms that support commercialization should be embedded within R&D frameworks to maximize economic returns.

### ***6.2.3 Macro-Level Enablers Strongly Influence Innovation Commercialization Outcomes***

STI financing, institutional linkages, and policy alignment significantly predict commercialization performance. A successful commercialization strategy must address knowledge gaps, especially those related to regulatory barriers such as restrictive intellectual property laws. Policies should reflect an in-depth understanding of the factors that attract or deter private sector investment in R&I, particularly in Uganda's economic context. Thus, there is a pressing need to identify effective and sustainable financing models such as crowd funding, for innovation that combines public, private, and international resources.

### ***6.2.4 Integrated Commercialization Frameworks Provide Comprehensive Solutions***

The validated model demonstrates that commercialization outcomes improve when micro- and macro-level factors are addressed simultaneously. Techno-business models must be tailored to local realities, including firm size, technological regimes, and socioeconomic conditions. Strategies should involve multilevel phases, including financing, development, diffusion, and legitimation, while addressing barriers and optimizing local impact.

## **6.3 Recommendations**

### ***6.3.1 Policy-Level Recommendations***

- a) Develop a unified National Commercialization Framework to guide STI actors.
- b) Increase R&D and commercialization funding to move toward international benchmarks.
- c) Strengthen policy coherence through harmonization across ministries and agencies.
- d) Create national innovation coordination platforms to integrate data and activities.

### ***6.3.2 Institutional-Level Recommendations***

- a) Enhance university, industry, and government linkages through joint R&D programs.
- b) Establish technology transfer offices in all public universities.
- c) Support incubation and acceleration programs that focus on market readiness and certification.

### ***6.3.3 Firm-Level Recommendations***

- a) Build firm capabilities in product development, IP management, and market analysis.

- b) Promote industry training programs in commercialization and innovation management.
- c) Encourage the adoption of digital and production technologies to accelerate scaling.

#### ***6.3.4 Recommendations for Future Research***

- a) Expand the framework to sector-specific commercialization models.
- b) Conduct longitudinal studies to assess commercialization trajectories.
- c) Integrate artificial intelligence (AI) and digital platforms into commercialization process research.

#### **6.4 Limitations of the Study**

While the findings offer valuable insights, they are specific to Uganda's regulatory and technological context and may have limited generalizability to other developing countries. Further research should investigate the applicability of these conclusions in countries with different innovation systems, regulatory environments, and economic conditions.

#### **6.5 Concluding Remarks**

Uganda's path to a vibrant, innovation-driven economy requires moving from isolated policies and fragmented initiatives to the deliberate, integrated, and sustained execution of the strategies outlined in this study. By adopting the proposed framework, Uganda can shift from being a consumer of imported technology to a creator and exporter of home-grown solutions, bridging the chasm between its considerable innovative potential and socioeconomic development.

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**APPENDICES: PAPERS I - VII**

## **PAPER I**

# National innovation system for resilience, transformation and sustainable development in Uganda: contextual analysis of the factors, actors and associated linkages

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## Abstract

**Purpose** – While the role of the National Innovation System (NIS) in promoting economic growth is well recognized, there remains a significant knowledge gap concerning how interactions among actors and learning processes within these systems facilitate innovation commercialization in Uganda. This gap hinders the effective design and implementation of policies aimed at boosting innovation-driven development in emerging economies. This study aims to explore the linkages and interrelationships among NIS actors in Uganda.

**Design/methodology/approach** – This study used systematic document reviews and case-study techniques. A systematic review based on the SPAR-4-SLR protocol evaluated the literature on Uganda's NIS, including policy and strategy documents, development frameworks, journal articles and working papers. This dual approach allowed for an in-depth analysis of policy documents and empirical examples, revealing complex mechanisms within Uganda's NIS. A content analysis tool facilitated the reduction of qualitative data through codification, theme development and the reporting of results.

**Findings** – This study explored the relationships among NIS actors, offering insights into using Uganda's unique institutional and economic landscape for sustainable growth. It identifies key drivers, such as improved collaboration between the government, industry and academia and strategic policy measures in technology transfer and innovation funding, which are essential for revitalizing Uganda's innovation ecosystem.

**Research limitations/implications** – This study presents a preliminary analysis of Uganda's NIS. Future studies should adopt a longitudinal approach to examine the evolution of NIS over time, including the impact of global technological advancements and policy changes on Uganda's innovation ecosystem. To elucidate the complex interrelationships within an NIS, subsequent research could employ network analysis or systems

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**Declarations: Data availability statement:** The data sets/documents used and analyzed during the current study are available from the corresponding author upon reasonable request.

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thinking methodology. These approaches would facilitate a more nuanced understanding of the interconnections and reciprocal influences among various NIS stakeholders.

**Practical implications** – The inclusion of the innovation, technology development and transfer (ITDT) program in National Development Plan III demonstrates that National Innovation System (NIS) incorporation into the country's development process is possible through a combination of policy/regulatory, market/economic and technical/technological factors.

**Originality/value** – This study significantly advances the understanding of innovation systems by detailing the intricate network of relationships within Uganda's NIS. This highlights the unexplored dimensions of learning and cooperation and offers a thorough analysis of the factors that enable innovation, which are crucial for promoting innovation in a developing country.

**Keywords** National innovation system, Resilience, Sustainable development, Transformation, Uganda

**Paper type** Research paper

## Introduction

The concept of a National Innovation System (NIS) is pivotal in fostering a country's resilience, transformation and sustainable development. Previous research has established a direct correlation between NIS, economic growth and social change (Fagerberg and Srholec, 2008; Chaminade *et al.*, 2018; Kurpayanidi, 2023). Moreover, the establishment and implementation of the NIS are critical factors in a country's success and its transition from an agricultural to a knowledge-based society. Several scholars have indicated that the extent to which a country adopts and uses innovation directly affects its resilience, change and progress (Spielman *et al.*, 2009; Perry, 2020; Aktar *et al.*, 2020). Given the critical importance of NIS as a guiding principle in the development process, countries have increasingly recognized the need to closely link innovation and development.

The NIS is a network of institutions that collaborate and coordinate to develop and implement innovative goods, processes and organizational practices. This system encourages collaborative efforts among universities, public research and development (R&D) organizations, private firms, financial institutions, technological support agencies, policymaking authorities and the government (Barasa *et al.*, 2017; Baláz *et al.*, 2023; Musabayana *et al.*, 2023). According to Hussen and Çokgezzen (2022) and Khelifaoui and Bernier (2023), the primary institutional players in the NIS are universities, public research and development organizations, private firms and financial institutions such as commercial banks, technological support agencies, policymaking authorities and the government.

Kreiterling (2023) and Staniulyte (2023) indicated that the significance of human capital and institutional entrepreneurship is widely recognized as a catalyst for changes in innovation systems. However, addressing the global challenge of sustainable development requires innovation that reconciles top-down and bottom-up approaches, emphasizing the role of actors, communities and their interactions, according to Jia (2021). In addition, the emerging purpose ecosystem plays a crucial role in transforming businesses to address the United Nations Sustainable Development Goals (SDGs), with private actors advocating for nonfinancial performance outcomes (Stubbs *et al.*, 2022).

Mulumba *et al.* (2017) noted the scarcity of literature exploring the importance of interaction and learning among NIS stakeholders in developing, employing and commercializing new products, processes and organizational practices in Uganda. A clear and comprehensive framework that facilitates the transformation of aspirations to use NIS for development into tangible activities is currently lacking (Fashina *et al.*, 2018; Bowman, 2019; UBOS, 2020; Okwakol *et al.*, 2022). Despite the explicit integration of NIS into the

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National Development Plan (NDP) III, this challenge remains unaddressed (Mulumba *et al.*, 2017; NPA, 2020; UNCTAD, 2020; World Bank, 2021).

Until recently, the development process in Uganda implicitly considered NIS as a tool for driving national growth, competitiveness and sustainable development. According to the 2022 Global Innovation Index, Uganda ranks 102 out of 129 countries (Dutta *et al.*, 2022; Alqararah, 2023), which is significantly low, particularly in terms of key transformational indicators, such as technological readiness and innovation (Dutta *et al.*, 2022; Alqararah, 2023). Specifically, the country's Gross Expenditure on Research and Development (GERD) was only 0.4% of its gross domestic product (GDP), which fell below the African Union (AU) recommended 1% (NPA, 2020; Sithole, 2020). Moreover, business expenditure on R&D was negligible at 0.01%, and the country filed approximately 250 patent applications with only two registrations (NPA, 2020; Sithole, 2020).

Lack of understanding of the structure and function of the NIS often leads to random and challenging investments in research and innovation, as highlighted by Noeh *et al.* (2023) and Wen (2023). It is crucial for researchers, scientists, innovators and technopreneurs to comprehend the connections and interactions among the various actors in Uganda's NIS and how they facilitate the innovation and commercialization process (Watkins *et al.*, 2015; Yan *et al.*, 2024). The proposed integrative framework aims to enhance the exploitation of the Science, Technology and Innovation (STI) value chain, maximize returns on investment and guide decisions on investments in research and innovation made by firms, government and development partners to achieve social and economic transformation.

While the significance of NIS in driving economic change has been recognized (Castellacci and Natera, 2013; Staniulyte, 2023), there is a substantial knowledge gap concerning how Uganda's distinct socioeconomic and institutional environment influences the efficacy of NIS connections and the functions of various actors within the system. Existing research has largely neglected the influence of informal networks and local innovation cultures on interactions between NIS participants in Uganda (Okumu and Buyinza, 2020; Salmon *et al.*, 2020), which could provide valuable insights into enhancing the system for long-term development. This study aims to address these gaps by conducting a comprehensive examination of the interactions, connections and learning processes among NIS actors in Uganda, emphasizing the impact of informal networks and indigenous innovation methods. Bridging these knowledge gaps is crucial for developing more effective policies and strategies that capitalize on local strengths and cultural practices to foster innovation, potentially leading to more robust and sustainable development outcomes.

In Uganda, NIS is a complex and diverse system that requires a comprehensive understanding of various factors, including effective STI policies (Aktar *et al.*, 2020; Yan *et al.*, 2024), social transformation (Liang and Li, 2023), human capital (Staniulyte, 2023) and purpose ecosystems (Stubbs *et al.*, 2022). To ensure sustainable development, it is essential that actors within the system, such as the government, the private sector and civil society, engage in coherent and interconnected interactions. In addition, the relationships between these actors and broader socioeconomic and ecological contexts are crucial for the resilience and transformation of Uganda's NIS.

## Literature review

### *National Innovation System a prerequisite for resilience, transformation and sustainable development*

The resilience, transformation and sustainable development of a country depends on its understanding of its NIS. The NIS consists of the connections, interactions and knowledge base of STI actors, which, when applied comprehensively, enable innovators across the NIS

to hone their skills, foster wealth creation and promote prosperity (Noeh *et al.*, 2023; Wen, 2023). When viewed in its entirety, NIS can serve as a productive mechanism that facilitates the generation, development and application of novel ideas and innovations to produce improved outcomes, processes and services, according to Staniulyte (2023) and Yan *et al.* (2024). Comprehending the intricate connections between institutional stakeholders engaged in innovation initiatives or procedures is vital to boosting a country's technical and economic performance (Chen and Ou, 2021; Fernandes *et al.*, 2022). The NIS emphasizes the intricate relationships among national development actors who constitute the foundation for the country's resilience, transformation and sustainable development:

**Box 1:** Policies impacting Uganda's National Innovation System

- Constitution of the Republic of Uganda 1995,
- Uganda Vision 2040,
- National Development Plan 2020/21–2024/25,
- National Science, Technology and Innovation Policy 2009,
- National Biotechnology and Biosafety Policy 2008,
- National Industrial Policy 2020,
- National Intellectual Property Policy 2019,
- Poverty Eradication Action Plan 2004/05–2007/08,
- Plan for Modernization of Agriculture 2006/07,
- National Health Policy 2001/02,
- Science Education Policy 2005,
- National Agricultural Research Policy 2004,
- National Environment Management Policy 1995,
- Information and Communication Technology Policy 2003,
- National Forestry Policy 2001,
- National Gender Policy 1997.

**Source:** UNCTAD (2020)

As indicated in Box 1, a well-functioning NIS integrates various government policies such as education, R&D and intellectual property (IP) protection to support sustainable economic development (Mulumba *et al.*, 2017; Al-Jayyousi *et al.*, 2023; Kurpayanidi, 2023). Furthermore, empirical evidence indicates that even small states with limited technology-based R&D resources can leverage an NIS to catch up economically, suggesting that it can serve as a catalyst for capacity building and transformation (Noeh *et al.*, 2023). However, this study had some limitations. For example, while China's NIS has contributed to its economic growth, it has been criticized for not significantly supporting the sustainability of innovation in small and medium-sized enterprises (SMEs), which suggests potential shortcomings in the inclusivity and scope of NIS (C. Jia *et al.*, 2020). Similarly, Taiwan's transition from information and communication technology (ICT) industrialization to a digital economy necessitates a reevaluation of its NIS to accommodate new digital technologies and innovation management challenges (Chen and Ou, 2021). These examples illustrate that, while an NIS is crucial, its design and implementation must be adaptive to the specific needs and stages of development of a country.

Although extant research has acknowledged the importance of interactions among NIS actors in Uganda (Mulumba *et al.*, 2017), there remains a paucity of comprehensive analysis regarding the specific mechanisms through which these interactions facilitate or hinder the commercialization of innovations. Uganda’s NIS emphasizes governmental and academic roles in innovation. However, comparable economies have successfully integrated the private sector and SMEs into their NIS frameworks, suggesting potential avenues for policy and strategic enhancements (Okumu and Buyinza, 2020; Salmon *et al.*, 2020). While the significance of human capital is widely recognized, the current literature inadequately addresses how Uganda’s NIS can leverage emerging technologies for sustainable growth, highlighting a critical area for future investigation.

Current research provides a limited understanding of how Uganda’s NIS facilitates environmental innovation, particularly in key economic sectors such as agriculture and energy (Twaha *et al.*, 2016; Mulumba *et al.*, 2017). This knowledge deficit is particularly significant given the global urgency surrounding climate change and sustainability issues. Furthermore, there is a notable lack of research on the inclusiveness of Uganda’s NIS, with minimal attention paid to the participation of women and underrepresented groups in the innovation landscape. Addressing this gap is crucial for ensuring that innovation benefits are distributed equally across all segments of society.

The NIS is essential for fostering resilience, transformation and sustainable development. This study provides a structured framework of innovation and economic growth. However, the success of an NIS depends on its ability to adjust to changing technological environments and support a wide range of sectors, such as SMEs and emerging industries. Studies have shown that a comprehensive and versatile NIS can contribute significantly to a country’s sustainable development and transformation (Chen and Ou, 2021; C. Jia *et al.*, 2020; Noeh *et al.*, 2022a, 2022b).

### Innovation generation process models

Table 1 presents the findings for the four innovation models. The first-generation model posits that all innovations stem from scientific advancements and that new industries arise

**Table 1.** Summary of the innovation generation process models

Generation	Innovation model	Period	Essence of the model
1	Technology push	1950s–late 1960s	Linear process
2	Market (need) pull	Late 1960s–first half of 1970s	R&D on customer wishes
3	Coupling model	Second half of 1970s–end of 1980s	Interaction of different functions
	Interactive model		Interaction with research institutions and market
4	Integrated model	End of 1980s–early 1990s	Simultaneous process with feedback loops; chain-linked model
5	Networking model	1990s	System integration and networks (SIN)
6	Open innovation	2000s	Innovation collaboration and multiple exploitation paths

Source: Meissner and Kotsemir (2015)

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mainly because of technological opportunities (Lüdeke-Freund, 2020; Bedoya Villa *et al.*, 2023). The second-generation model emphasizes the market-driven nature of innovation, suggesting that it is based on market demand rather than technological change. The third model focuses on the interplay between technological capabilities and market demand as well as the convergence of these factors within an innovative enterprise. The fourth-generation model emphasizes the parallel process of innovation, which connects business operations through various feedback loops (Lüdeke-Freund, 2020; Bedoya Villa *et al.*, 2023).

The fifth-generation networking model, which is based on the chain-linked model and includes a strategic component of collaborating with company integration, expanding the relevance of information and communication technologies and using expert systems and networks (Lüdeke-Freund, 2020; Bedoya Villa *et al.*, 2023), has been defined as an integrated, parallel, flexible, networked innovation process since the early 1990s. The sixth-generation model emphasizes the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand markets for the external use of innovation (Asad *et al.*, 2023). The open innovation paradigm posits that organizations employ both external and internal ideas, as well as internal and external pathways to the market, to enhance their technology (Table 1).

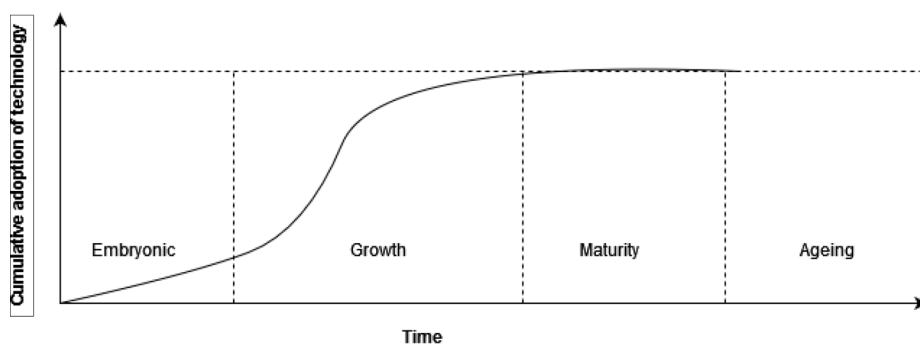
Studies by Lüdeke-Freund (2020) and Bedoya Villa *et al.* (2023) emphasize the significance of employing cyclical and dynamic models to improve firm adaptability in a globalized economic environment. This study highlights that the innovation generation process models have shifted from rigid, linear structures to more flexible, iterative and open systems. The literature suggests that incorporating external inputs, embracing disruptions and fostering adaptability are crucial for successful innovation. These models encompass control theory-based frameworks, open innovation and cybernetic models, among others, each with strategic value in managing innovation within organizations (Bedoya Villa *et al.*, 2023).

### **Frameworks and models of technological innovation and diffusion**

Investing more in R&D is considered the most effective strategy for increasing the output of a new technology, a process referred to as technology or supply push (Scott, 2019; Mallinson, 2021). However, the demand-pull approach posits that demand for products and services plays a more significant role than advancements in knowledge in driving innovative activities. The innovation paradigm of research, development, demonstration and deployment (RDD&D) integrates and clearly articulates both supply-push and demand-pull approaches to technological innovation (Mallinson, 2021).

Several technology diffusion models are intended to explain the elements that impact the acceptance rate of new technologies, leading to the formulation of the technology S curve, as depicted in Figure 1. The diffusion of innovation theory (Mallinson, 2021; Mishrif and Khan, 2023) emphasizes the conditions that contribute to consumer acceptability of innovative products, resulting in sustained product acceptability and greater sales. Consumers' knowledge of the advantages that new products offer over their competitors as well as their motivation levels are crucial factors in determining their purchasing decisions (Scott, 2019; Mallinson, 2021).

The S-curve assumes that limited public awareness of a technology restricts its adoption rate. Conversely, the probit model suggests that diverse organizations may not adopt new technologies simultaneously because of variations in their objectives and competencies (Bedoya Villa *et al.*, 2023; Lüdeke-Freund, 2020). In the Probit model, diffusion occurs when various types of entities decide to embrace new technologies (Fasano and Durante,



Source: Mallinson, 2021

Figure 1. Technology S-curve

2022). Research and Development (R&D), the technology lifecycle and technology diffusion models offer a linear, sequential depiction of technological advancement. Nonetheless, contemporary perspectives challenge this notion, highlighting the importance of intricate, systemic interactions between supply and demand factors (Fasano and Durante, 2022) as well as the role of stakeholders and entities in the creation and implementation of technologies within a broader socio-technical context.

According to Scott (2019) and Mallinson (2021), the purpose of these models is to elucidate the development, adoption and propagation of innovation within and between organizations and societies. Several scholars have indicated that there is no unified field of study; however, a vast array of theories and methodologies have evolved over time and have enhanced our understanding of these phenomena (Lüdeke-Freund, 2020; Bedoya Villa *et al.*, 2023; Mishrif and Khan, 2023). Notably, despite the variety of models, specific recurring themes and factors have been identified as having significant impacts on the innovation and diffusion processes. These include the size and configuration of the firm, market influence, profitability and actions of firms, as well as the role of leadership, compatibility of innovation with norms and values and attitudes toward innovation (Scott, 2019; Mallinson, 2021).

According to Mallinson (2021) and Dissanayake *et al.* (2022), predictors of innovation adoption can change throughout the diffusion lifecycle. Furthermore, state wealth and population size may become more important as policies spread. The frameworks and models of technological innovation and diffusion offer a conceptual understanding of how new technologies emerge and are embraced by markets and societies. These models highlight the multifaceted nature of innovation processes and various determinants that can influence the rate and extent of diffusion. Although the existing literature provides valuable insights, further research is needed to refine these models and address the gaps in our understanding of innovation adoption, as pointed out by Dissanayake *et al.* (2022).

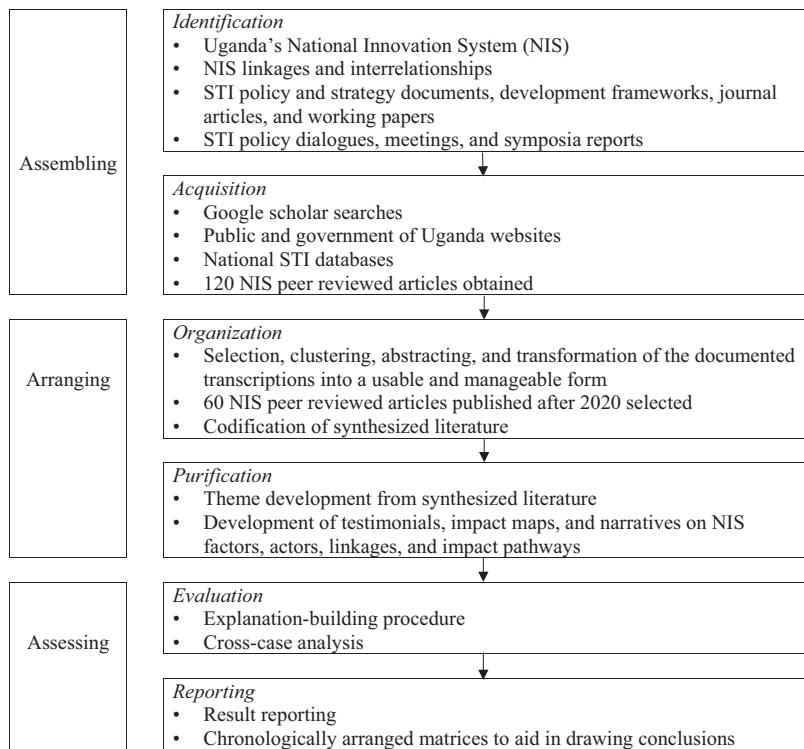
## Method

### *Study design and approach*

This study was conducted using a systematic approach that combined both document review and case study methods. To ensure transparency and replicability, we carried out a systematic

literature review of the NIS in accordance with the Scientific Procedures and Rationales for Systematic Literature Review (SPAR-4-SLR) protocol (Paul *et al.*, 2021; Scheuer and Thaler, 2022). This protocol consisted of three stages and six substages that progressed sequentially (Figure 2): assembly, which entailed the identification and acquisition of NIS literature that had not been synthesized; arranging, which involved the organization and purification of NIS literature that was in the process of being synthesized; and assessing, which involved the evaluation and reporting of NIS literature that had been synthesized.

Documents were selected based on their relevance to Uganda's NIS, publication timeframe (January 2000–December 2023), and availability in English. Non-peer-reviewed articles and those that did not specifically address Uganda's NIS were excluded from the study. Case studies were selected based on their significant influence on Uganda's NIS, encompassing various Science, Technology, Engineering and Mathematics (STEM) sectors. Each case study evaluates its impact on innovation, resilience and sustainable development prior to inclusion. The methodology integrated a systematic document review with case studies to provide a comprehensive analysis of Uganda's NIS literature and detailed insights from specific innovation instances. Although the SPAR-4-SLR protocol and case study analysis offer extensive insights, they may not fully capture the informal innovation



Source: Authors' own work

Figure 2. SPAR-4-SLR Protocol for the study

activities in Uganda's rural areas. Future research could employ ethnographic approaches to investigate these aspects further.

### *Data collection*

*Document reviews.* An extensive review of literature on Uganda's NIS was conducted, encompassing policy and strategy documents, development frameworks, journal articles and working papers. Appropriate data and literature were employed to provide context and complement the document reviews and case studies. The primary focus of this review is on the nation's transformation and development frameworks, including the STI Policy and Plan, Industrialization Policy, Community Development Model, National Development Planning Framework and Uganda Vision 2040. Using Google Scholar, over 120 NIS peer-reviewed articles were obtained, of which 60 published after 2020 were selected for this study. In addition, other documents pertaining to the country's transformation and development as well as reports on STI policy dialogues, meetings and symposia were examined.

The investigation examined patent applications and grant trends pertaining to Ugandan innovators through an analysis of data from the Uganda National Council for Science and Technology (UNCST) and Uganda Registration Services Bureau (URSB). This analytical approach facilitated the identification of domains that exhibited substantial innovation potential or commercialization challenges. The study In addition incorporated structured interviews with key stakeholders in the NIS, including representatives from universities, R&D institutions, private enterprises, financial organizations and governmental bodies. These interviews explored various aspects such as the impact of extant policies, impediments to innovation and the significance of international collaborations in fostering innovative activities.

*Case studies.* Case studies of various NIS framework conditions were used to highlight the significant and substantial effects of the transformative actions and interactions of different NIS stakeholders, according to [Kruachottikul et al. \(2023\)](#) and [Staniulyte \(2023\)](#). Various STEM sectors were examined through carefully selected case studies employing a standardized framework to evaluate critical elements, including policy support, financial mechanisms, collaborative networks and market access. This methodological approach elucidates exemplary practices and significant challenges in the innovation trajectory of each sector. These case studies were analyzed individually using a structured framework that encompasses context, rationale, goals, outcomes, lessons learned and crucial recommendations. This framework was employed to generate testimonials, impact maps and narratives of impact pathways. The integration and triangulation of evidence from diverse sources offers context and facilitates additional contextual analysis of the factors, actors and associated linkages within Uganda's NIS.

### *Data analysis*

Data analysis was performed by aligning the themes obtained from document reviews and case studies. The data were analyzed using a content analysis tool that enabled the reduction of qualitative data through codification, theme development and result reporting ([Mihas, 2019](#); [Lester et al., 2020](#)). Themes were developed through iterative analyses of the coded data, with the research team engaging in deliberations to refine themes and ensure their accurate representation of the underlying information. Thematic analysis employed a two-step coding methodology. Initially, open coding was applied to identify preliminary themes related to NIS actor interactions. Subsequently, axial coding was implemented to establish connections between these themes and to elucidate how policy frameworks and technology transfer facilitated these interactions. The documents were read, evaluated and synthesized to

pinpoint the factors, stakeholders and circumstances or settings that promote innovation within the ecosystem. The notes from each phase were combined to develop the different codes. Next, the codes were collated by naming each phase, the codes from each phase were summarized, and themes were assigned to the codes. Finally, the themes were summarized to produce the results of the study. An explanation-building procedure was employed in a cross-case analysis, according to Plotz (2020), to gain further insight into the NIS factors, actors and associated linkages. The synthesized information was organized into chronologically arranged matrices to aid in drawing the conclusions.

### Findings and discussion

#### *Framework conditions for the national innovation system in Uganda*

Figure 3 illustrates Uganda's NIS, adapted and modified according to the Organization for Economic Cooperation and Development (OECD, 1999). This modified framework highlights the essential conditions that shape Uganda's research, innovation and commercialization ecosystem, including policy/regulatory, technical/technological and market/economic contexts. The NIS framework encourages collaboration and knowledge exchange among stakeholders to create, use and monetize novel products, processes and organizational strategies.

*Determinants of the NIS policy and regulatory context.* The UNCST was tasked with formulating the first STI Policy and Implementation Plan (MFPED, 2009, 2012). This policy unifies the previously fragmented aspects of STI into a cohesive and all-encompassing policy framework, emphasizing the importance of STI in accelerating productivity, enhancing competitiveness and promoting long-term development (MFPED, 2009). The policy underwent a thorough assessment of the STI environment, and its connections aligned with the NDP I (2010/11–2014/15). The strategy revealed that the extensive resource capacity gaps present in the entire STI sector are incompatible with Uganda's development objectives.

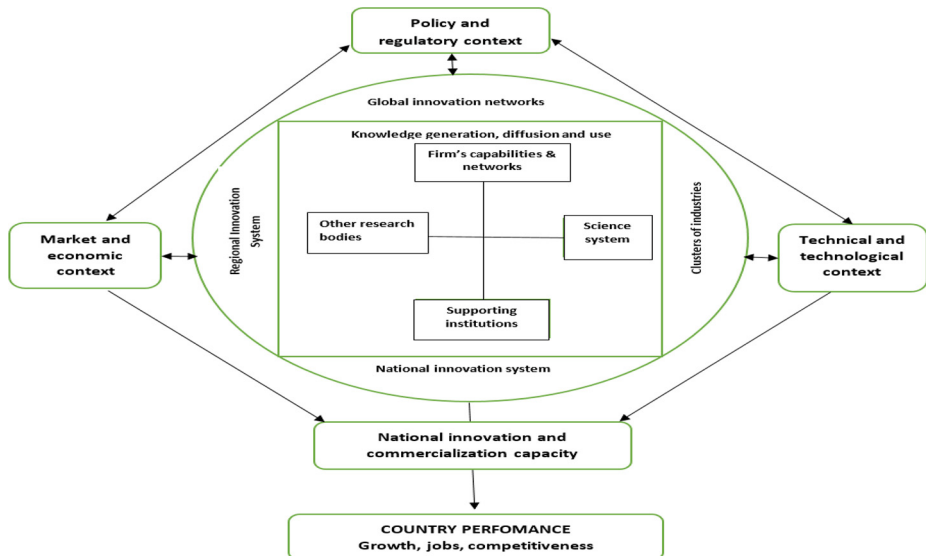


Figure 3. Uganda's national innovation system, modified according to OECD (1999)

To address this, the policy established a set of guidelines to direct the application of STI policy instruments to the national development and transformation agenda (MFPEd, 2009).

The policy formulated in 2009 by the Ministry of Finance, Planning and Economic Development (MFPEd) anticipated potential challenges to Uganda's vision of development, including slow progress in transformation, development and productivity growth (MFPEd, 2009; UNCTAD, 2020). However, several obstacles arose during the implementation of the strategy, some of which were related to the reorganization of governance procedures. Initially, the policy was under the purview of the MFPEd, but it was later transferred to the Ministry of Education, Science, Technology and Sports and the Ministry of Science, Technology and Innovation. The Science, Technology and Innovation Secretariat of the Office of the President (STI-OP) is currently spearheading the implementation of this policy.

According to Fosci *et al.* (2019) and MOSTI (2019), insufficient funds in multiple partner ministries, departments and agencies (MDAs) that collaborate with the UNCST to implement the strategy pose significant challenges. In addition, the absence of performance metrics, assessment criteria and timeframes in policy design and inadequate monitoring and evaluation (M&E) structures impedes policy implementation (NPA, 2019; UNCTAD, 2020; United Nations, 2020). Consequently, it is difficult to objectively evaluate the policy because of the lack of data for collection and monitoring. This hinders policy coordination in the STI sector and limits opportunities for interaction and learning, thus leading to more effective and practical STI policies. However, the STI Plan has made significant strides in implementing the M&E framework (NPA, 2019; UNCTAD, 2020; United Nations, 2020).

The STI policy continues to face challenges in precisely defining its policy area, with inadequate emphasis on the program's innovation component and the role of businesses and entrepreneurs. There is a mixed commitment to STI principles in policy as well as some reluctance to include innovation as a basic component of the strategy (NPA, 2019; UNCTAD, 2020; United Nations, 2020). Sectors and industries are rarely identified as users and providers of information and skills capable of transforming ideas into innovations and, therefore, into economic and social value, as they are not anticipated to play a significant role in the process. This view permeated most of the government entities that were considered STI stakeholders. According to most experts, the private sector, particularly industry and manufacturing, can only play a minor role in STI policy and is often seen as a funder rather than a partner in development programs (NPA, 2019; Stubbs *et al.*, 2022; UNCTAD, 2020).

To address its fragmented STI policy landscape, Uganda could potentially emulate Rwanda's efficacious model of an integrated STI policy framework that has effectively harmonized innovation support across diverse sectors (Barasa *et al.*, 2017; Nahikiriza, 2023). Through implementation of a comparable unified strategy, Uganda has the potential to enhance policy alignment and execution efficacy. This approach may necessitate the establishment of a centralized STI governing body to synchronize policy initiatives and ensure consistent support for innovation across all sectors.

*Determinants of the National Innovation System technical and technological context.* The entities responsible for promoting technology transfer in Uganda primarily focus on the technical and technological aspects. However, innovations that are integrated into products and services have not achieved significant commercial success. The technology transfer process faces significant obstacles and is not aligned with a country's developmental objectives (Fashina *et al.*, 2018; Bowman, 2019; Stubbs *et al.*, 2022). To achieve its transformation agenda, as outlined in the 2030 Agenda for Sustainable Development, it is essential to provide stronger political support for the technical and technological processes in Uganda.

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Uganda's industrial economy is relatively small-scale. The agricultural sector primarily depends on subsistence rather than exports, and the process of technology transfer is viewed as a separate issue, both technological and financial in nature, distinct from the broader context of the STI policy. Although several industries have isolated initiatives, their influence on national technical and technological processes and national sustainable development has been negligible (NPA, 2019; UNCTAD, 2020; United Nations, 2020).

The processes of technology transfer are widely considered to be significant elements of international technology exchanges and flows and are characterized by the transfer of foreign technologies that are adapted to meet local conditions. However, these procedures often fail to consider that the success of a technology embodiment, whether in the form of a product or service, is ultimately determined by the market performance (Abbas *et al.*, 2018; Stubbs *et al.*, 2022). Overemphasis on foreign technology transfer procedures has a negative impact on the development of national technology transfer systems and can hinder the ability of both enterprises and industries to absorb knowledge and technology.

As highlighted by Abbas *et al.* (2019) and Stubbs *et al.* (2022), the national technology transfer framework should establish connections and interactions among the actors necessary for a successful NIS, the primary objective of which is to facilitate technology transfer. In this regard, a business-oriented environment, access to financial support and the presence of a skilled and professional workforce enhance companies' technological absorptivity, which is a crucial prerequisite for successful technology transfer.

The issue of transferring technology to address SDGs is widely recognized (Stubbs *et al.*, 2022). However, it is important to note that interventions should not be limited to technological aspects of the challenge. Entrepreneurial methods and innovative tools should be considered, and potential investors should be engaged in successfully implementing and maintaining the recommended solutions.

While the importance of human capital in fostering innovation is recognized, Uganda experiences a substantial deficit of qualified personnel in STEM fields (Okwakol *et al.*, 2022). Further research is necessary to elucidate the underlying factors contributing to this shortage by examining both the output of the educational system and the demands of the labor market. Furthermore, although institutional entrepreneurship is acknowledged as a catalyst for transformation, the specific obstacles innovators encounter when navigating institutional frameworks have not been sufficiently explored.

*Determinants of the National Innovation System market and economic context.* According to Okwakol *et al.* (2022) and Kurpayanidi (2023), a comprehensive, cross-sectoral policy approach to promoting the dual roles of businesses and industries within the STI sector can only be achieved through the implementation of an NIS policy framework and fostering a culture of collaboration and outreach. Ensuring access to and affordability of ICT, energy, efficient and effective transportation, logistical infrastructure and capital is crucial for promoting innovation-led growth and building a strong foundation for progress (Bowman, 2019).

Enhanced communication between governments and businesses is crucial, particularly for the taxation of startups and developing enterprises. It is essential to create a more flexible tax environment that accommodates creative startups considering their low R&D spending, as highlighted by Zhu *et al.* (2020) and the World Bank (2021). Moreover, Uganda should focus on increasing GERD from 0.4% to 1%, as recommended by the AU (NPA, 2020; Sithole, 2020). However, it is important to note that growth in GERD is primarily driven by increased demand from businesses and industries rather than isolated academic R&D.

Uganda's educational system faces several challenges, including a dearth of qualified educators and curricula that may not fulfill the competency requirements of students,

industries and employers. Universities and research institutions must collaborate more closely with sectors and companies to cultivate STEM graduates with innovative attitudes, talent and self-assurance suitable for the workforce (Kapiriri *et al.*, 2020; Okwakol *et al.*, 2022).

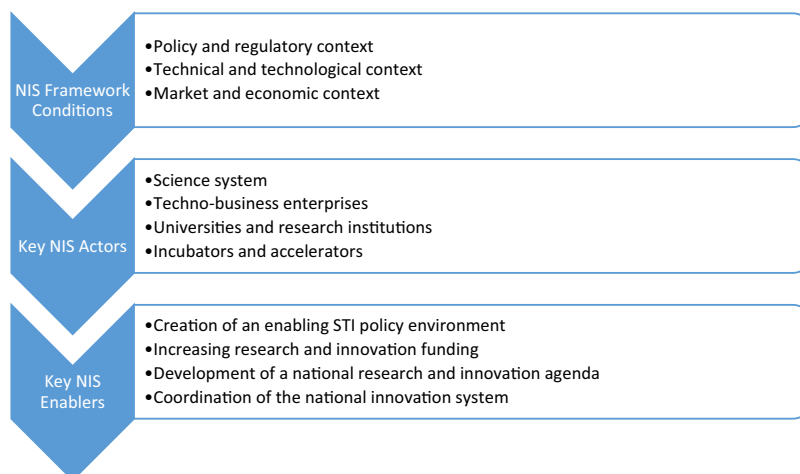
The National Intellectual Property Policy elucidates the subject of intellectual property rights (IPR) and delineates several crucial concerns, such as IPR enforcement and IP commercialization. However, implementing IP policies requires the cultivation of human and financial resources (MOJCA, 2019; NPA, 2019; UNCTAD, 2020). Policymakers must consistently emphasize the significance of IPRs in enhancing a nation’s innovation potential, transformation and development. Nevertheless, employing IPR to safeguard and monetize traditional knowledge and genetic resources may contradict a country’s development goals.

Further investigation is warranted to elucidate the dynamic interplay between market demand and technological advancement in Uganda’s NIS. Specifically, examining the reciprocal processes by which market needs stimulate technological progress and how these innovations shape market demands could reveal novel avenues for fostering innovation. Analyzing empirical examples in which consumer demand has directly precipitated technological developments in Uganda or comparable economies might yield valuable, actionable insights for both policymakers and innovators (Mulumba *et al.*, 2017).

#### *Interaction of the factors, actors and constraints within the national innovation system*

Collaboration and acquisition of knowledge among actors within the NIS results in the advancement of products, processes and organizational innovation. Figure 4 illustrates the framework conditions, key actors and facilitating elements of the NIS.

*The national science system.* In recent policy debates, science has rarely been discussed in isolation but rather in conjunction with technology and innovation. However, scientific advancements do not always lead to societal progress or innovation. Consequently, the need



**Source:** Authors’ own work

**Figure 4.** NIS Framework conditions, key actors and enablers

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to view science from a broader perspective has become increasingly evident. Researchers have acknowledged that the concept of science is closely linked to technology and innovation, as noted by Hanlin *et al.* (2020) and the Canton (2021). It is not only the pursuit and accumulation of knowledge through research that is crucial but also its practical application in technology and various forms of innovation.

This study highlights the importance of science systems and a broader network of institutions, actors, policies, information and communication channels in shaping the trajectories and contents of scientific activities in Uganda's NIS. Science systems cannot be viewed in isolation from other interconnected systems, including research, knowledge and innovation (Hanlin *et al.*, 2020; Aktar *et al.*, 2020; Okwakol *et al.*, 2022). These systems have an impact on various other sectors, such as agriculture, health, energy, mining and manufacturing, as well as financial, commercial and cultural systems. Therefore, the broader concept of science systems encompasses research, knowledge, technology and innovation, as supported by Hanlin *et al.* (2020) and Okwakol *et al.* (2022).

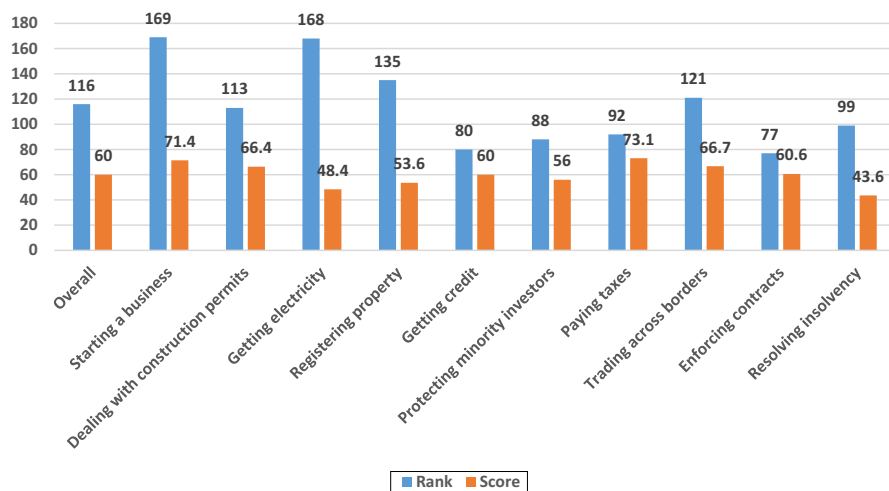
The expectation in Uganda is that science-related organizations must conduct science for the common good and ensure that the direction of science is shaped by the country's most pressing socioeconomic needs (Kapiriri *et al.*, 2020; Okwakol *et al.*, 2022). However, the country's science system is unlikely to achieve this because of several historical challenges, including weak scientific institutions, reliance on foreign support for R&D, lack of institutional research structures, insufficient reproduction of scientific and academic staff and low levels of scientific enrollment in Ugandan society. To address these challenges, the country must focus on strengthening and disseminating practical knowledge on how the national science system operates.

*Role of techno-business enterprises.* The success of technological advancements relies on the specialized expertise of the techno-business enterprise, as well as its entrepreneurial acumen (Kwesiga, 2019; Farooq *et al.*, 2021; Kolade *et al.*, 2021). Although Uganda's existing business environment is consistent with regional averages, it may not be suitable for achieving the national development objectives. Enhancing the business environment is crucial for revitalizing and advancing NIS (Kwesiga, 2019; World Bank, 2021). The Global Competitiveness Index (GCI) of the World Economic Forum ranks 117th among 140 countries in terms of its framework for international competitiveness (Schwab and Zahidi, 2020). The two most important pillars of competitiveness are business dynamism and the capacity to innovate. According to Kwesiga (2019) and the World Bank (2021), Uganda performs considerably better on the pillars of business dynamism and innovation than on other essential pillars of competitiveness such as health, skills and infrastructure.

The effectiveness of business policies and institutional frameworks was evaluated according to annual business reports published by the World Bank (World Bank, 2018). In these assessments, Uganda ranks lower than other countries such as Rwanda, Kenya and Zambia. Although Uganda has shown improvements in securing loans, enforcing contracts and paying taxes (World Bank, 2018; UNCTAD, 2020), there is room for improvement.

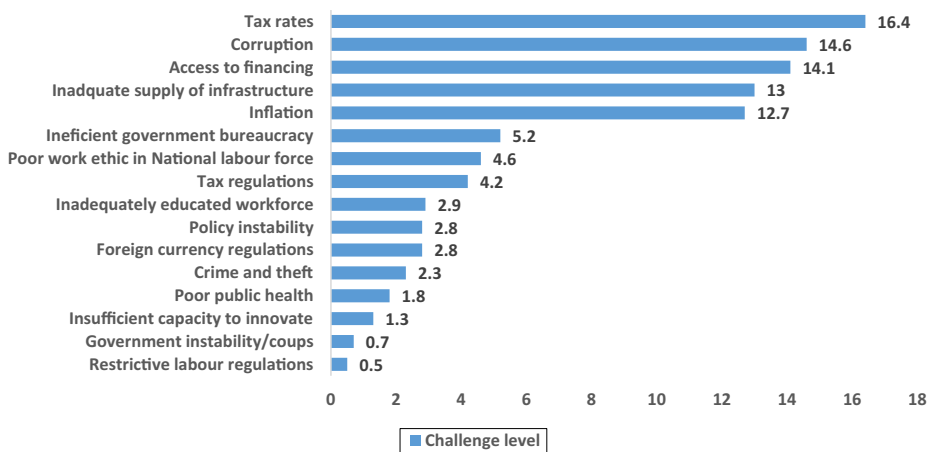
Establishing a business entity, registering IPR and engaging in international trade present formidable obstacles to the country (World Bank, 2018; Farooq *et al.*, 2021; Abate and Sheferaw, 2023), as depicted in Figures 5 and 6. Despite these challenges, Uganda possesses a favorable environment for innovation because of its progressive stance on entrepreneurship and entrepreneurial risk-taking. Remarkably, Uganda surpasses several categories of entrepreneurial risk, business development, workforce diversity, multi-stakeholder collaboration, R&D investment and academic publishing.

According to the Global Entrepreneurship Monitor (GEM), Ugandan entrepreneurs are viewed positively. They exhibit a strong sense of perceived opportunity and ability, with



Source: World Bank, 2018

Figure 5. Rankings on doing business by topic for Uganda



Source: World Bank, 2018

Figure 6. Most problematic factors for doing business

minimal fear of failure, and a significant portion of the middle-aged population intends to establish new businesses soon (Hill *et al.*, 2022). Entrepreneurship is acknowledged as a respected social status and desirable career path. Nevertheless, only a small fraction of aspiring entrepreneurs anticipate that their future ventures will contribute substantially to innovation or job creation.

According to [World Bank \(2018, 2021\)](#), Ugandan business owners possess significantly higher levels of self-perceived potential, entrepreneurial abilities and talent than the regional and global averages. They are not deterred by failure and are optimistic about their ability to establish new businesses soon. This trend is particularly evident in women's increasing participation in entrepreneurship ([UBOS, 2020](#); [Okwakol et al., 2022](#)). Ugandan entrepreneurs diversify their investments across a wide range of microenterprises as a fundamental risk management strategy rather than focusing on a single business venture.

Promising indicators of a positive mindset toward entrepreneurship do not always lead to thriving businesses because of various obstacles. Unfavorable government policies and inadequate financing are typically cited as the primary challenges. Consequently, instead of launching a single enterprise, Ugandan entrepreneurs often opt to manage multiple small and micro-businesses ([Bowman, 2019](#); [UNCTAD, 2020](#); [World Bank, 2021](#)).

The UNCST conducted an innovation survey between 2011 and 2014 using the guidelines set forth in the Oslo Manual ([UNCST, 2016a](#); [Sithole, 2020](#)). The survey targeted companies in mining, manufacturing and service sectors. Companies in the health and education sectors as well as those in the public sector, agriculture, fishing, forestry and trade, were excluded from participation. A total of 589 enterprises with 10 or more employees were surveyed in 6,475 industrial and service businesses.

The following text presents information on the revenue and workforce of companies as well as data on the prevalence and forms of innovation in Ugandan enterprises. According to the data, many Ugandan businesses have modest innovation levels ([Table 2](#)). During the reference period, the majority (77%) of all firms with 10 or more employees in the industrial and service sectors participated in innovation-related activities ([UNCST, 2016a](#); [Sithole, 2020](#)). From 2011 to 2014, the industry sector was more active in innovation activities than the services sector, but the position was reversed for investment-related elements of innovation. These companies accounted for 85.7% of total revenue and 73.8% of the workforce.

Fixed investments in technology and innovation in Uganda are insufficient to support development efforts, as shown in [Tables 3 and 4](#), indicating that investments in technological innovation activities totaled nearly US\$700m in 2014. The service sector invested \$511m, whereas the industry sector invested \$175m. Over 64% of the innovation investment, or approximately \$450m, is spent purchasing machinery, equipment and software. Internal R&D receives less than 10% of the total investment ([UNCST, 2016a](#); [Sithole, 2020](#)).

The purchase of external R&D is the second-largest area of investment, underscoring two crucial issues that expose the restricted technological capabilities of Ugandan enterprises

**Table 2.** Types of innovation in firms

Type of innovation	Total (%)	Industry (%)	Services (%)
Enterprises with innovation activity	77	85.7	73.8
Product only innovators	11.2	7.2	12.8
Process only innovators	12.7	13.7	12.4
Product and process innovators	48.2	59.2	44.1
Enterprises with 'ongoing only' activities	2.4	2.4	2.4
Enterprises with 'abandoned only' activities	1.9	2.7	1.6
Enterprises with ongoing and abandoned activities	0.5	0.5	0.5
Enterprises without innovation activities	23	14.3	26.2

**Source:** UNCST (2016)

**Table 3.** Investment in innovation by sector and ownership, in USD

Category	Ownership		Sector		All firms
	Ugandan	Foreign	Industry	Services	
In-house R&D	29,230,769	30,269,231	4,192,308	55,384,615	59,615,385
Purchase of external R&D	125,000,000	8,153,846	3,842,308	129,230,769	133,076,923
Acquisition of machinery, equipment and software	378,461,538	65,000,000	158,461,538	285,000,000	442,307,692
Acquisition of other external knowledge	7,653,846	6,884,615	888,462	13,653,846	14,538,462
All other innovation activities	10,038,462	28,730,769	8,384,615	30,346,154	38,846,154
Total innovation expenditure	550,000,000	138,461,538	175,384,615	511,538,462	688,461,538

Source: UNCST (2016)

**Table 4.** Investment in innovation by firm size – number of employees, in USD

Category	No. of employees				All firms
	250+	50–249	20–49	1–19	
In-house R&D	1,653,846	3,130,769	18,692,308	36,000,000	59,615,385
Purchase of external R&D	1,530,769	3,807,692	118,846,154	8,961,538	133,076,923
Acquisition of machinery, equipment and software	51,538,462	338,461,538	20,769,231	33,038,462	442,307,692
Acquisition of other external knowledge	161,154	4,807,692	2,769,231	6,807,692	14,538,462
All other innovation activities	492,308	5,961,538	1,823,077	30,461,538	38,846,154
Total innovation expenditure	1,530,769	3,807,692	118,846,154	8,961,538	133,076,923

Source: UNCST (2016)

(UNCST, 2016a; Sithole, 2020). First, technology users lack the ability to initiate technological advancements. Second, the actual figures are minimal, representing approximately 0.22% of a country's GDP. Consequently, it is essential to place greater value on, and increase, private investment in innovation to achieve a significant impact, as noted by Zhu *et al.* (2020).

*Contribution of universities and research institutions.* According to Zhu *et al.* (2020) and Lefebvre *et al.* (2022), technological advancements and innovative ideas must possess a unique value proposition that sets them apart and attracts client attention. Although technology can offer effective solutions to prevailing challenges and benefit the environment positively, its commercial viability is crucial to its success. Without a clear path to profitability, such technologies may not gain the trust of investors, who tend to prioritize investments that offer promising returns.

Uganda's stock of human capital in the STI is limited (Bowman, 2019; Okwakol *et al.*, 2022). As of 2016, there have been over 2,000 active researchers in all fields, according to UNCST (2016b) and Sithole (2020). The quality of the education system is crucial for building human capital potential. Although Uganda's education system has made significant progress, there are challenges in improving STEM education, particularly in vocational training. Shifting the focus of science-related professions to higher education could increase the supply of skilled professionals in the STEM fields.

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The NIS is designed to encourage entrepreneurship and economic specialization by increasing IP ownership. This system enhances the interaction between academia and industry and makes research projects more relevant for both scientific and commercial purposes (Liang and Li, 2023; Yan *et al.*, 2024). These findings have the potential to improve students' ability to place themselves in the industry. The protection of IPRs generated by universities creates a platform for industry-academia collaboration in strategic innovation (Son *et al.*, 2022). This also creates a market for ideas, which serves as a significant incentive for innovators and encourages additional investment in university programs. The protection of IPRs is crucial for commercializing innovations to generate profits and growth.

The NIS enhances a country's innovative capacity by increasing the appeal of foreign direct investment (FDI), which brings new technologies and products (Liang and Li, 2023; Yan *et al.*, 2024). Innovation often arises from the fusion of domestic knowledge and technological and organizational inputs from foreign enterprises. This fusion is crucial for boosting a country's innovation capabilities. The NIS will significantly bolster the quality of human capital, especially in the field of STEM, which is vital for a country's innovation, competitiveness and long-term growth.

*Infrastructure support function of incubators and accelerators.* Providing infrastructure support is crucial for businesses to achieve profitability. Various organizations, such as start-up incubators, accelerator programs, research institutes and technology parks, can offer valuable assistance to enterprises (Kwesiga, 2019; Atiase *et al.*, 2020; Kolade *et al.*, 2021). Incubation refers to nurturing and expanding new small businesses in the early stages of development by providing an adaptable infrastructure, business development strategies and human resources. According to Atiase *et al.* (2020) and Kolade *et al.* (2021), a country's development and transformation agenda aims to facilitate rapid development and launch of firms and prototypes. Incubators can help scientists and innovators to establish and accelerate the growth and success of their prototypes through a comprehensive business model.

A business accelerator serves as a conduit to connect emerging businesses with mentors, investors and other resources, thereby facilitating the growth of prosperous enterprises. These accelerators are commonly used by businesses that have progressed beyond their incorporation stage (Kwesiga, 2019; Atiase *et al.*, 2020; Kolade *et al.*, 2021). In essence, they have reached the nascent stages of development and have achieved a measure of self-sufficiency because of a successful incubation period; however, they still require guidance and peer support to attain maturity.

Bowman (2019) and Kwesiga (2019) highlighted that the proliferation of incubators in Uganda has contributed to an increase in their activities. A variety of incubators, such as Outbox and The Innovation Village, focus on ICT-related businesses. However, other incubators are emerging in more traditional sectors such as food and agro-processing. Notably, Makerere University's Food Technology and Business Incubation Center (FTBIC) and Pharm-Biotechnology and Traditional Medicine Center (PHARMBIOTRAC) accelerator at the Mbarara University of Science and Technology (MUST) are important players in this space. PHARMBIOTRAC is one of the 24 Higher Education Centers of Excellence (ACE II) programs established at MUST in 2017 with World Bank funding. Its primary objective is to cultivate a critical mass of specialized and skilled human resources capable of advancing traditional medicine and Pharm-Biotechnology for African socioeconomic development (Kwesiga, 2019; UNCTAD, 2020).

Unlike the Uganda Industrial Research Institute, the FTBIC focuses on small and medium-sized businesses, placing a greater emphasis on job creation than on innovation. The FTBIC provides business incubation support services, common user facilities and services to

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help strengthen traditional product commercialization (Kwesiga, 2019; UNCTAD, 2020). For newly established businesses, primary concerns are job creation and import substitution.

A new development can be discerned in the operations of accelerators in Uganda, which, however, faces significant shortcomings in its NIS, according to Kwesiga (2019) and UNCTAD (2020). These gaps in Uganda's NIS have severely undermined technological, ICT and digitally oriented initiatives. The Innovation Village nurtures a technical resource network as well as a network of potential investors. By harnessing novel advantages from the digital economy, the Innovation Village programs and projects yield products, experiences and enterprises. The Innovation Village connects individuals within a community to create, prototype, test, scale and bring innovative and entrepreneurial ideas to the market (Bowman, 2019; Kwesiga, 2019; UNCTAD, 2020).

Accelerators, especially incubation activities, are reportedly hindered by the fragmentation of Uganda's NIS as they typically function independently and are unable to use connections with other key players in the system, including banks, research institutes, large enterprises and foreign investors (Kwesiga, 2019; Atiase *et al.*, 2020; Kolade *et al.*, 2021). The limited availability of technical capabilities, as well as the fragmentation of various physical infrastructures, restricts the impact of the few emerging acceleration initiatives. The NIS significantly contributes to the development of a competitive market structure by providing incentives for companies to develop innovative and improved products, processes and business models to attract consumers and maintain market share.

#### *Science, technology and innovation financing*

*National research and development funding.* According to the NPA (2020) and Okwakol *et al.* (2022), public research institutes and universities in Uganda primarily provide STI financing. The average GERD in Uganda between 2014/15 and 2018/19 was approximately 0.4% (NPA, 2020; Sithole, 2020; UNCTAD, 2020a). This figure is significantly lower than that of the Republic of South Africa, which reported a GERD of 0.8%–1%, and Sweden, which spends approximately 4% of its GDP annually on R&D (Schwab and Zahidi, 2020; Canton, 2021). Uganda spent 0.01% of its GDP on business R&D and received approximately 250 patent applications but only two patent registrations (NPA, 2020; Sithole, 2020; UNCTAD, 2020).

Uganda's Technology Achievement Index (TAI) is projected to rise from 0.15 in the disadvantaged group to 0.21 by 2020, placing the country in the dynamic adopter category. This indicates that Uganda will achieve middle-income status or SDG 1 to eradicate extreme poverty (NPA, 2020; Dutta *et al.*, 2022; Alqararah, 2023). The third result area is enhanced R&D intensity or increasing GERD as a proportion of GDP from 0.5 to 1%, as proposed by the AU. This is a crucial milestone for science, technology and innovation strategy for Africa in 2024 (African Union Commission, 2014; Sithole, 2020). According to the STI Statistical Abstract, 2016, GERD decreased from 0.5% in 2010 to 0.23% in 2014, whereas TAI decreased from 0.15% in 2010 to 0.14% in 2014 (UNCST, 2016b; Sithole, 2020).

Governments and development partners largely fund STI programs and initiatives. For instance, in FY 2016, the Ugandan government spent an estimated 42% of the total R&D funding, while development partners contributed 51% and other sources contributed 7% (UNCST, 2016b; Sithole, 2020; UNCTAD, 2020). The government primarily covered administrative expenses such as utility bills, maintenance costs and employee wages, while private actors made minimal contributions. Currently, Ugandan scientists rely on foreign grants and donations for their research. However, the domestic funding arrangements for STI are becoming increasingly stable and sustainable. Countries such as South Africa and Sweden have established separate public financing mechanisms for STI, including funding

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for scientists, researchers and innovators, as well as a nationwide grant facility awarded on a competitive basis (Schwab and Zahidi, 2020; Canton, 2021).

Businesses typically require a significant amount of capital to develop their discoveries because of limited resources. Specific financial structures must be devised to address the financial demands of enterprises that have completed the R&D phase and that seek to bring their products to the market. The most well-known method for meeting R&D financial needs is collaborative research with other institutions. This approach has been recommended by various researchers, including Bryson *et al.* (2020) and Zhu *et al.* (2020).

Tech businesses and R&D organizations should adopt a comprehensive approach to commercialize technological advancements that extend beyond technology and encompass the administration of the entire commercialization process (Freudenreich *et al.*, 2020; Farooq *et al.*, 2021). Contractual arrangements, licensing, assignments, joint ventures and spin-off companies are available to commercialize technological advancements. The URSB is responsible for implementing the Uganda Intellectual Property Policy by commercializing Ugandan technologies (MOJCA, 2019; NPA, 2020).

According to Zhu *et al.* (2020) and Lefebvre *et al.* (2022), limited access to financing has a significant impact on innovation, which cannot be overstated. Therefore, it is crucial to recognize that funding R&D does not always equate to funding innovation. Although investment in R&D is an essential aspect of an innovation ecosystem, organizations and industries require financial resources to enhance their innovation capabilities and achieve greater competitiveness and commercial success at both national and global levels.

*Contribution of government bodies.* Governance in the scientific community involves the establishment of policies, regulations, laws and strategies for STI. In Uganda, the Cabinet approved the STI Policy and Plan in 2009 and 2012, respectively, thus providing a framework for STI investment, coordination and administration (MFPED, 2009, 2012). In 1990, the UNCST Act established a national S&T fund that served as a legal framework for managing R&D funds (GOU, 1990). The Millennium Science Initiative funding facility, a joint initiative between the World Bank and Ugandan government, was successfully launched in 2006 and managed by the UNCST until 2012. In addition, the UNCST has implemented several other national and international STI funding programs on a bilateral or trilateral basis, such as the National Science, Technology and Innovation Program (NSTIP), to strengthen national research and innovation capacities, as noted in the MOSTI (2019) and UNCTAD (2020).

In keeping with its in-house integrated research grant management, the UNCST has played a pivotal role in the design and implementation of a continent-wide competitive research grant program under the Science Granting Council Initiative, which is primarily funded by a consortium of Canadian, British, Swedish, German and South African donors (Hanlin *et al.*, 2020; Sadeski *et al.*, 2023). As a result, the UNCST can manage national research grants and use donor support to address national Science and Technology (S&T) development priorities with global appeal, as outlined in the United Nations 2030 Agenda for Sustainable Development (United Nations, 2016; UNCTAD, 2020). By streamlining this competitive financing structure, UNCST can also facilitate bilateral and multinational Science and Technology (STI) cooperation, which would greatly benefit Ugandan scientists and represent a significant step toward incorporating STI into the national development process.

The Parliamentary STI Committee is responsible for addressing STI concerns in the national legislative assembly, including the allocation and supervision of resources in the STI sector. The Uganda National Academy of Sciences (UNAS) is an institution that assists with STI governance. UNAS was established in 2000 as a platform for providing balanced,

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credible and factual opinions on the contemporary STI challenges facing the country. To develop effective strategies for integrating STI into the development process, organizations in the STI sector must communicate with each other to establish mechanisms for translating STI policies into actions and a strategy for mediating relationships between other actors in the innovation system (Bowman, 2019; UNCTAD, 2020; Okwakol *et al.*, 2022).

The UNCST created the National Science, Technology, Engineering and Innovation Center, the Technology and Business Incubation Center and the Manufacturing Machining and Skills Production Center (MOSTI, 2019; UNCTAD, 2020). The STI infrastructure provides workspaces, incubation facilities, analytical labs and other shared user facilities to assist innovators in commercializing their technologies, processes and innovations.

Uganda's NIS does not fully capitalize on the advantages of international cooperation. Future initiatives could prioritize establishing bilateral innovation partnerships with nations with well-developed NIS structures. These collaborations have the potential to facilitate technology transfer, enhance research capabilities and strengthen local institutions through shared expertise and resources. The efficacy and impact of these partnerships can be substantially improved by identifying specific areas for collaborative efforts such as sustainable energy technologies and the development of digital infrastructure (Mulumba *et al.*, 2017; Fashina *et al.*, 2018; Okumu and Buyinza, 2020; Salmon *et al.*, 2020).

#### *National Innovation System linkages, sustainability and development challenges*

According to NPA (2019) and United Nations (2020), Uganda boasts a comprehensive policy framework for implementing regional and international development, characterized by a high level of coherence and vertical alignment. However, the role of STI differs across various policy domains, indicating that it was formulated without adequate coordination. Agenda 2030 for sustainable development is a holistic agenda that aims to promote economic, environmental and social development, recognizing that eradicating poverty is the most pressing challenge for long-term development (United Nations, 2016; NPA, 2019).

The Government of Uganda has implemented Agenda 2030 for sustainable development, which is a key component of NDP III and Vision 2040. NDP III covers fiscal years 2019/20–2024/25, during which the 2030 Agenda and its SDGs have been identified as important policy priorities, as highlighted by the NPA (2019) and the United Nations (2020). Uganda was among the first countries to align its national development planning framework with SDGs. The government claims that the strategy is adapted to the country's development and transformation framework for 76% of the SDG targets (NPA, 2019, 2020).

According to the United Nations (2020), the SDG coordination framework and roadmap serve as a foundation for establishing practical initiatives that will drive Uganda toward inclusive, low-carbon and sustainable development. These documents provide the basis for the National Planning Authority (NPA) to develop a plan that will enable all key stakeholders to contribute to achieving the SDGs. The plan acknowledges the importance of involving development partners and nongovernmental stakeholders in the implementation of policies, as well as the role of data, monitoring and evaluation in achieving the desired outcomes, as indicated by NPA (2019). The NPA highlighted the need to establish an enabling environment conducive to achieving the SDGs in Uganda.

The Green Growth Development Strategy (GGDS) recommends that Uganda reassess its development and transformation framework to achieve equitable socioeconomic outcomes, in accordance with the NPA (2016) and United Nations (2020). The GGDS's key areas align with NDP III, emphasizing the importance of fair economic growth and environmental sustainability. The strategy addresses several crucial policy elements, including service provision, competitiveness, value addition and behavioral change mechanisms. In addition,

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the GGDS recognizes that green growth requires structural modifications and human capital development (NPA, 2016; UNCTAD, 2020). However, GGDS's limited scope and failure to acknowledge the critical roles of private firms, businesses, industry, universities and academia present significant challenges.

However, the GGDS Roadmap failed to recognize the significance of STI in the implementation process (NPA, 2016; UNCTAD, 2020). Subsequently, the STI sector must intensify its collaboration with established institutions to achieve the objectives of Agenda 2030 for Sustainable Development. It is essential to emphasize the central role STI play in fostering an NIS that drives long-term growth through the innovation activities of enterprises, entrepreneurs, industries and sectors.

#### *Key National Innovation System enablers and intervention areas*

The implementation of the ITDT program provisions of NDP III and Vision 2040 within Uganda's NIS would necessitate considering the following interventions for successful execution.

*Creation of an enabling Science, Technology and Innovation policy environment.* The NIS approach emphasizes the need for a comprehensive strategy that encompasses various MDAs as well as the private sector. Addressing the interconnected challenges within and across the STI system requires coordinated and concentrated efforts. In Uganda, the NIS faces limitations because of the absence of a systematic approach to tackling current STI challenges. To overcome these shortcomings, additional institutional strengthening measures are necessary to integrate all the components of the system. Underdeveloped STI data and statistical frameworks require enhanced capacity-building efforts to facilitate collection, storage, dissemination and analysis of STI-related information.

Closing the existing gaps in Uganda's STI policy will require policymakers to take the following actions: increasing support for innovation in the STI sector and government MDAs; improving coherence, coordination and alignment among the various policy areas that make up the STI policy framework; enhancing the ability to execute, analyze and amend the STI policy throughout consecutive policy cycles; generating genuine transformational development to boost industrial output; and engaging the private sector. These interventions require a significant shift in agricultural output, from subsistence farming to commercial value chains and industrial production.

*Increasing research and innovation funding.* The need for increased investment in the STI sector necessitates the implementation of novel approaches to sectoral investment financing. This includes increasing private participation in public-private partnerships (PPPs) and FDI. Currently, a country's investment in innovation-related research is insufficient. Uganda currently lacks a formal mechanism for funding long-term research and innovation because of shifting government priorities and the absence of an approved innovation and research framework. Research and innovation funding is a viable means of increasing research and developing innovative programmes. This impact can be enhanced by providing grantees with capacity-building and technical assistance.

Uganda's R&D investment remains minimal, as evidenced by the GERD of 0.4%. This low investment level has contributed to declining national competitiveness in STI. This trend is at odds with the AU initiative, which has set a target GERD of 1% in all African countries. To address this issue, governments and development partners must play a significant role in promoting R&D. Foreign R&D funds are particularly important in Uganda. In addition, it is crucial for the government and development partners to prioritize skill development over schooling in STEM education. Modifying the curriculum may be necessary to encourage

independent thinking and creativity in learners. This is particularly important, given Uganda's limited capacity to attract FDI.

Uganda has faced numerous hurdles in the realm of business finance that impede growth and hamper innovation. Despite the government's provision of a broad range of financial services, access to these services for SMEs is limited because of a variety of factors, including high interest rates, restrictive collateral requirements and multiple processing fees. These challenges are likely to persist and continue to constrain the innovation capacity of SMEs. In addition, the standard obstacles encountered when starting a business exacerbate this constraint.

*Development of the national research and innovation agenda.* Uganda offers numerous opportunities to improve its research and innovation capabilities. Given the increasing demand for stakeholders, it is crucial to enhance institutional capacity by implementing novel models of institutional transformation and growth. Although computer and internet usage is currently limited, the ongoing expansion of these technologies is likely to support the growth of businesses, industries, academic institutions and ICT innovation centers. Uganda has greater potential for skilled human resources in business, administration and law, which are critical skills that drive improvements in the NIS.

The country's relatively equitable ease of doing business, particularly the objective and supportive access of enterprises to government resources, contributes to a favorable business climate for innovation. In addition, when corporate tax rates are high, a nation offers tax incentives to attract significant investment firms. Uganda's flourishing IP law environment presents an opportunity for its NIS, although enforcement may temporarily impede the preservation of granted rights.

Accordingly, solutions to present obstacles must be proffered to promote and safeguard advancements in research and innovation. Providing financial support to pioneering prototypes through seed capital is a promising strategy. Furthermore, bolstering capacity-building measures such as skill development programs may pave the way for more rapid economic growth by using a NIS framework.

*Coordination of the national innovation system.* Uganda's NIS has been plagued with poor coordination, which has hindered the functioning of important institutions involved in STI. This lack of coordination has resulted in gaps in STI support and the duplication of activities. The multifaceted nature of STI in Uganda has led to the responsibility for science being shared among several line MDAs, resulting in a fragmented system that fails to provide effective coordination of STI development, associated R&D processes and outputs. Establishing a national research agenda is expected to address these issues through coordination with the NIS.

The inability to coordinate the NIS has hindered the public's appreciation and adoption of new, emerging and transformative technologies. This failure impedes the achievement of institutional goals and socioeconomic transformation and development. Although some of these challenges can be resolved through institutional approaches, many require systemic and multi-sectoral solutions.

## **Conclusion**

### *Theoretical implications*

Existing NIS frameworks predominantly focus on the innovation processes of advanced economies, thereby failing to adequately address the specific challenges and prospects encountered in developing nations, such as Uganda. These countries face distinct issues, including inadequate infrastructure, heterogeneous socioeconomic landscapes and disparate levels of technology adoption, which are not sufficiently captured in the current NIS models.

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According to Kurpayanidi (2023) and Wen (2023), NIS is a critical component in comprehending how countries may optimize their innovation capabilities to achieve sustainable development. The stability and adaptability of the NIS are crucial because they determine its capacity to maintain balance and adjust to change, which is fundamental for continual innovation, as highlighted by Noeh *et al.* (2023).

Notably, while the NIS framework has been implemented in various countries, there are differences in its conceptualization and effectiveness between developed and developing countries (Fernandes *et al.*, 2022). For example, small countries such as Brunei have demonstrated that possessing an appropriate NIS can lead to economic catching up through capacity building and digitalization, according to Noeh *et al.* (2022a, 2022b). Conversely, in China, the concentration of NIS in large state-owned enterprises has resulted in less attention being paid to the sustainability of innovation in SMEs (Jia *et al.*, 2020). This indicates that the structure and focus of the NIS can significantly influence its capacity for transformation and resilience.

NIS has significant theoretical implications for Uganda's ability to achieve sustainable development, transformation and resilience. Research indicates that an effectively structured NIS can promote economic growth by encouraging innovation and adaptability (Fernandes *et al.*, 2022; Noeh *et al.*, 2023). However, the success of an NIS in fostering resilience and transformation may depend on how it is conceived and implemented, with particular emphasis on inclusivity and support for SMEs (Jia *et al.*, 2020; Abate and Sheferaw, 2023). Therefore, adopting a strategic and inclusive approach to NIS in Uganda is crucial for realizing its sustainable development objectives.

Future iterations of Uganda's NIS should implement strategies that actively engage and support SMEs and grassroots innovators, recognizing their potential to enhance resilience and promote sustainable growth (Okumu and Buyinza, 2020; Salmon *et al.*, 2020). This may encompass establishing dedicated funding mechanisms, mentorship programmes and innovation hubs tailored to address the specific needs of these groups. The NIS framework in Uganda can be enhanced by developing sector-specific innovation strategies that address unique challenges and leverage opportunities within key industries, including agriculture, health care and renewable energy (Mulumba *et al.*, 2017; Fashina *et al.*, 2018). This approach would facilitate a more targeted and effective method for fostering innovation that aligns with developmental priorities.

To enhance the efficacy of Uganda's NIS, it is imperative to strategically align it with the nation's educational policies. This alignment should prioritize the advancement of STEM education and vocational training programs to equip the workforce with the requisite skills for innovation-driven economic growth (Okwakol *et al.*, 2022). Furthermore, Uganda's NIS can be substantially strengthened through the implementation of strategies that leverage digital transformation. These strategies may encompass the promotion of digital literacy, facilitation of digital entrepreneurship and allocation of resources toward digital infrastructure development (Bowman, 2019; Pius and Owin, 2024). Such initiatives would not only enhance the innovation ecosystem but also position Uganda more advantageously to participate in the global digital economy.

#### *Policy implications*

The government and policymakers must ensure effective implementation of STI policies to promote interaction and learning among NIS actors in Uganda. The integration of resilience and sustainability within social-ecological systems highlights the importance of social transformation and behavioral changes in problem solving (Aktar *et al.*, 2020; Okwakol *et al.*, 2022). Notably, while innovation systems are crucial in driving sustainable futures

globally, research connecting NIS with sustainable development is scarce, particularly at the national level (Fernandes *et al.*, 2022). This gap indicates that Uganda could benefit from developing a NIS to support sustainable development, which would necessitate systemic changes and sustainable consumption behaviors (Mulumba *et al.*, 2017; Bowman, 2019).

Furthermore, the transformation of NIS in transition economies such as Uganda emphasizes the significance of human capital and institutional entrepreneurship in stimulating institutional change (Okwakol *et al.*, 2022), which may be applicable to Uganda's innovation system development. In essence, policy implications for Uganda's NIS should concentrate on devising a robust communication strategy to bridge information gaps and promote public awareness (Bowman, 2019), encourage social behavior modifications for environmental problem-solving (Kapuriri *et al.*, 2020) and enhance the NIS to support sustainable development (Mulumba *et al.*, 2017). Institutional entrepreneurship can drive this transformation (Okwakol *et al.*, 2022), and these efforts should align with the broader objective of achieving the SDGs (NPA, 2019; United Nations, 2020).

This study underscores the significance of STEM education in promoting innovation; however, it fails to provide an in-depth analysis of how current STEM education policies effectively enhance innovation capabilities among young Ugandans. Future policy initiatives should focus on developing a comprehensive strategy for digital transformation encompassing investments in digital infrastructure, programs to improve digital literacy and incentives for digital entrepreneurship (Okwakol *et al.*, 2022). To address the fragmented nature of Uganda's NIS, policy recommendations should include the establishment of a national council for innovation that brings together stakeholders from key sectors to coordinate innovation efforts and exchange best practices. Future innovation policies should incorporate principles of sustainability to ensure that innovation contributes to Uganda's developmental objectives. Furthermore, policies should aim to enhance the inclusivity of the innovation ecosystem, ensuring that women, rural populations and underrepresented groups actively participate in innovation processes (Nahikiriza, 2023).

#### *Ideas for future research*

Future research on NIS in Uganda could benefit from focusing on several key areas. A valuable area of investigation is the efficacy of the current policy frameworks and their implementation in promoting STEM education. This is particularly important, as gaps in STI policy and implementation may impede educational achievement (Okwakol *et al.*, 2022). Another area of consideration is the integration of financial innovation within the NIS framework, as demonstrated in China (Yan *et al.*, 2024). Exploring such strategies could provide insights into how they might enhance the system effectiveness and promote green innovation in Uganda.

According to Wen (2023), digital transformation has a significant impact on national innovation mechanisms, with the potential to enhance technology governance with local characteristics. Exploring the social aspects of innovation processes, particularly in the context of addressing environmental challenges through urban agriculture, may provide valuable insights into fostering behavioral change and social transformation in Uganda (Fashina *et al.*, 2018). The notion of innovation resilience, which encompasses both stability and adaptability, can be more thoroughly explored and applied in Uganda to comprehend how businesses can maintain their innovation efficiency while adjusting to change (Bowman, 2019).

Future research could extend this to the creation of a capacity development framework for higher education institutions regarding disaster resilience, which could be adapted to enhance research and innovation capacity in Uganda (Okwakol *et al.*, 2022). Therefore,

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future studies should investigate the integration of gender-responsive policies in STEM education, the function of financial and digital innovation in NIS, the social dynamics of innovation in addressing environmental challenges and the concept of innovation resilience. In addition, a framework for enhancing the capacity of an ecosystem for disaster resilience can be modified for application in the Ugandan context. By pursuing these research directions, Uganda's NIS could achieve resilience, transformation and sustainable development.

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Subsequent studies should conduct a comprehensive analysis of Uganda's existing NIS-related policy frameworks and identify specific implementation deficiencies. One potential avenue of inquiry could be to investigate the barriers impeding effective policy execution in promoting STEM education and private-sector innovation (Okwakol *et al.*, 2022; Nahikiriza, 2023). Such research might use a multifaceted approach, incorporating policy evaluation, interviews with key stakeholders and examination of successful NIS models in comparable contexts. Further research could explore the impact of financial innovation on the productivity and efficacy of Uganda's NIS, with an emphasis on specific financial instruments (such as venture capital and crowdfunding) and their integration into the Ugandan context.

Subsequent studies should investigate the impact of digital technologies on Uganda's NIS, with particular emphasis on their role in facilitating collaboration among NIS participants and enhancing access to global markets for Ugandan innovations. This could encompass an analysis of case studies focusing on digital platforms that connect Ugandan innovators with international collaborators and investors as well as the implementation of surveys to assess the adoption and influence of digital tools among Ugandan researchers and entrepreneurs (Bowman, 2019; Pius and Owin, 2024). A comprehensive investigation could explore the social dimensions of innovation in relation to Uganda's environmental challenges by concentrating on methodologies to foster collaborative innovation processes across diverse societal groups. Future research should aim to establish a framework for evaluating and enhancing the resilience of Uganda's NIS, particularly in the face of economic and environmental disruptions (Mulumba *et al.*, 2017). This may involve quantitative research assessing the resilience of innovation processes in Ugandan enterprises complemented by qualitative case studies of firms that have successfully adapted to change.

#### *Limitations of the study*

This study presents a preliminary analysis of Uganda's NIS. Future studies should adopt a longitudinal approach to examine the evolution of NIS over time, including the impact of global technological advancements and policy changes on Uganda's innovation ecosystem. To elucidate the complex interrelationships within an NIS, subsequent research could use network analysis or systems thinking methodology. These approaches would facilitate a more nuanced understanding of the interconnections and reciprocal influences among various NIS stakeholders.

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## **PAPER II**



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## Innovation and Commercialization Characteristics of Techno-Business Firms in Uganda: An Overview of Firm Processes, Strategies, and Challenges

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The role of techno-business firms in shaping the innovation and commercialization processes in Uganda has been the focus of extensive research and analysis. The objective of this study is to provide a comprehensive understanding of the contributions of techno-business firms to the innovation and commercialization landscape in Uganda. To accomplish this, qualitative and quantitative research methods were employed using interviews and observational approaches. These methods involve gathering evidence, including observations and interviews with techno-business entrepreneurs. By examining the various factors that influence the growth of these firms, such as their approaches to Research and Development (R&D), marketing, and partnerships, this study sheds light on the ways in which techno-business firms drive innovation and commercialization in Uganda. This study indicates that R&D and Intellectual Property (IP) protection are vital components of firms' innovation and commercialization initiatives. The study underscores the importance of grants or subsidies as the primary financing mechanism for firm activities. The study highlights that product or innovation development depends on collaborative agreements, adjustments to current products, and internal idea generation. This study reveals innovation and commercialization disparities and proposes remedies to bridge these gaps. This ultimately fosters transformative growth by enhancing industrial production and strengthening the connections between techno-business firms and the industrial sector.

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**INTRODUCTION**

The development of firm innovation and commercialization processes has a crucial impact on industrialization and economic growth (Min et al., 2020; Butnik-Siverskyi et al., 2024). It enables the transformation of theoretical concepts into practical applications, streamlines work processes and techniques, and enhances access to information and knowledge, ultimately bolstering economic competitiveness. The advancement of techno-business development strategies can also support a shift in product development and value addition by fostering the establishment of new businesses and industries that facilitate the commercialization of new products and processes (Lekashvili & Bitsadze, 2021; Loganathan & Subrahmanya, 2022; Butnik-Siverskyi et al., 2024).

The importance of global trends underscores the necessity for firms to commercialize their innovations to sustain a competitive advantage or to venture into overseas markets. The trend towards accelerated innovation and commercialization not only benefits innovators but also raises the bar for rivals. Successfully commercializing innovations empowers techno-business firms to penetrate existing markets or create new ones, resulting in sustained industrial leadership and long-term viability. Previous research has linked successful commercialization to a firm's resources, human resource practices, top management teams, and the external environment (Min et al., 2020; Gong et al., 2021; Pererva et al., 2024).

The Government of Uganda (GoU) emphasizes technological innovation and commercialization to drive economic growth and sustainable development, as demonstrated by its Science, Technology, Innovation Policy (MFPED, 2012), National Development Plan (NPA, 2020), and

National Vision 2040 (NPA, 2007). Understanding the significance of innovation and commercialization is critical to Uganda's economic growth and prosperity. However, the success of policies and strategies in fostering innovation and commercialization hinges on their design and implementation within the context of innovation systems (Mulumba et al., 2017; Wen, 2023).

According to Ecuru et al. (2014), techno-business firms in Uganda primarily engage in incremental and adaptive innovations within the formal manufacturing sector with a focus on in-house development and international collaboration. However, local universities and research organizations do not actively participate in innovation processes, which can enhance their innovation capabilities. The study suggests that despite political will, coordination among stakeholders remains weak, and the role of techno-business firms in driving innovation and commercialization is still emerging.

Techno-business firms typically face intense competition and must develop suitable business models to effectively commercialize new products and realize their economic potential (Hussen & Çokgezen, 2020; Jian & Hongxia, 2023). In emerging economies, technological entrepreneurship is fostered through connections between major technology firms and small enterprises, which contribute to industrial growth (Usman et al., 2024). A firm with specialized technological capabilities may choose to commercialize its products alone or adopt a hybrid strategy depending on factors such as competition and financial position (Mukhtar et al., 2021). Research has shown that open innovation business models are positively associated with successful technology commercialization, suggesting that being open can lead to shorter

development times and a larger proportion of sales from new products (Kolade et al., 2021).

Techno-business enterprises in Uganda have considerable influence on the country's innovation landscape by contributing to incremental and adaptive innovations. This study aims to provide a comprehensive understanding of the contributions of techno-business firms to the innovation and commercialization landscape in Uganda. The potential of these firms has not been fully realized because of inadequate engagement with research institutions and an underdeveloped commercialization ecosystem. To address this issue, it is essential to fortify collaboration among firms, universities, and policy mechanisms to facilitate technology transfer and entrepreneurship. Noya and Taneo (2023) emphasized the importance of strengthening these interactions to enhance innovation output. Additionally, improved interactions with knowledge-intensive services, as highlighted by Kiefer et al. (2019), are crucial for fostering innovation in these firms.

## Literature review

### *Towards innovation and commercialization framework development*

Uganda has directed its efforts towards the development of a framework for innovation and commercialization, and recent initiatives have demonstrated the potential for cultivating scientific and technological capacity that could influence local innovation (Bowman, 2019). The Millennium Science Initiative (MSI), the involvement of universities such as Makerere and Mbarara, and the establishment of incubators suggest developing infrastructure to support innovation. Nevertheless, the absence of a coordinated mechanism for science, technology, and innovation (STI) policy stakeholders continues to be a hurdle (Guimón, 2013).

While Uganda has taken measures to encourage innovation, such as obtaining exemptions from the Trade Related Aspects of Intellectual Property Rights (TRIPS) system, the country's pharmaceutical sector has begun to establish

partnerships that foster innovation, indicating a shift towards higher-tech products such as diagnostics (Kpiriri et al., 2020). In contrast, broader issues relate to the commercialization of intellectual property rights (IPRs), and the need for legal and institutional support for innovation has been identified (Nahikiriza, 2023). Additionally, increased investment in Research and Development (R&D) and the implementation of policy measures to stimulate the commercialization of R&D are prerequisites (Hogan et al., 2022).

Countries around the world are increasingly recognizing the significance of innovation in driving economic growth and creating value. Consequently, many governments are revamping their innovation systems to remain competitive. In 2009, the Ugandan government introduced a comprehensive Science, Technology, and Innovation (STI) Policy to provide institutional and infrastructural support to produce goods and services as part of the country's development plan (MFPED, 2009). This initiative, when combined with other government efforts, university undertakings, industry contributions, and the participation of development partners, serves as a starting point for the formulation of more extensive and inclusive innovation policies and strategies in the country and surrounding areas.

Although Uganda has taken steps to promote STI through initiatives such as MSI, there is a need for better coordination and a cohesive policy framework to fully utilize these efforts in product innovation (Guimón, 2013). The experiences of other countries and the importance of legal frameworks can provide valuable insights for Uganda to enhance its innovation and commercialization efforts (Min et al., 2020; Butnik-Siverskyi et al., 2024). To strengthen these efforts, R&D investment is crucial for Uganda's growth.

### *Innovation and commercialization policy framework*

The Ugandan policy framework for innovation and commercialization is intricate and encompasses diverse sectors and stakeholders.

The government of Uganda has recognized the importance of STI in addressing challenges and promoting economic growth. Initiatives such as MSI and the participation of universities such as Makerere and Mbarara demonstrate the government's commitment to fostering innovation (Guimón, 2013). Furthermore, the growth of biotechnology and biosciences in Uganda is contingent upon government support for STI, which includes establishing a national science funding facility, promoting private sector commercialization of bioscience innovations, and enhancing institutional governance systems (Onapa et al., 2018, Nahikiriza, 2023).

The formation of policies for innovation and commercialization is significantly impacted by various sector policies and legislative acts, including the National Industrialization Policy of 2008, the National Agricultural Research Act of 2005, and the Uganda National Health Research Act of 2011. These policies are rooted in constitutional provisions that mandate the state to promote science and technology. Policies, such as the National Science, Technology, and Innovation Policy of 2009 and the National Biotechnology and Biosafety Policy of 2008, have provided a comprehensive framework for investment in research and innovation. However, it is essential to ensure that these policies are supported by clear implementation plans, and that they possess the capacity necessary for effective execution.

However, challenges exist in coordinating STI policies among stakeholders and commercializing university research. Despite the government's demonstrated political will for STI development, as evidenced by its investment in initiatives such as MSI, a more effective mechanism for policy coordination and stronger technology development and commercialization at universities is necessary (Nahikiriza, 2023). Moreover, the broader context of innovation and commercialization policy frameworks highlights the importance of collaboration among the government, industry, and academia (Noya & Taneo, 2023). Uganda has been actively working on developing its innovation and commercialization policy framework with

significant government investment and initiatives aimed at bolstering its STI capacity. Despite these efforts, challenges remain in effectively coordinating policies and enhancing commercialization.

### *Financing innovation and commercialization*

Funding for innovation and commercialization in Uganda is mostly provided by international or foreign agencies, the government, and not the private sector. Unlike middle- and high-income countries, where private investment is the primary source of innovation and commercialization, the private sector in Uganda is not yet capable of making significant investments in R&D (Sithole, 2020). Additionally, the scarcity of venture capitalists to support the commercialization of research results implies that the government has the largest responsibility for financing research and innovation in Uganda. Although R&D spending as a percentage of the Gross Domestic Product (GDP) has varied over the past five years, ranging between 0.2% and 0.5%, most of these funds come from abroad (UNCST, 2016). This level of spending falls short of the recommended minimum of one percent of GDP for R&D by the African Union (African Union Commission, 2014).

Addressing the financing of innovation and commercialization in Uganda is a multifaceted issue that necessitates the coordination of various stakeholders and mechanisms. The government has demonstrated strong dedication to advancing STI through initiatives such as MSI and fostering collaboration between industry and research institutions (Guimón, 2013). Despite these efforts, Uganda's innovation system is still in its nascent stage, characterized by limited technological development and commercialization.

Uganda's infrastructure development has played a significant role in its progress. Although these arrangements exist, they are generally thought to be beneficial for Uganda's development, provided they adhere to international standards and yield positive development outcomes (Ogwang & Vanclay, 2021). This infrastructure can indirectly promote the commercialization of innovations by

improving accessibility and connectivity. Crowdfunding, a novel financing model, has emerged in East Africa and Uganda. Although non-financial return models are more prevalent, equity- and loan-based crowdfunding are gaining traction. It is essential to pay regulatory attention to Fintech models to maximize their potential benefits while mitigating risks (Yin & Chang, 2021; Moon, 2022). This finding suggests an opportunity for innovative financing mechanisms to support Ugandan entrepreneurs.

The MSI was a substantial financial investment in R&D and innovation that received a total of USD 3.35 million from the Government of Uganda (GOU) and an additional United States Dollars (USD) 30 million from the International Development Association. This initiative, which ran from fiscal years 2006/2007 to 2012/2013, aimed to promote science- and technology-driven economic growth by training qualified scientists and engineers and conducting high-quality research (Guimón, 2013). The project allocated approximately USD 23 million to research grants (46%), undergraduate science and engineering curriculum development (53%), and cooperative projects with the private sector (1%) across various fields including engineering and technology (36%), medical and health sciences (28%), agriculture (19%), crosscutting themes (11%), and natural sciences (6%).

The remaining funds were allocated to increase the institutional capacity of the Uganda Industrial Research Institute (UIRI) by five million US dollars as well as to finance outreach programs, policy studies, monitoring, and evaluation. The UNCST was responsible for overseeing the implementation of the MSI project, while an independent Technical Committee comprising members from both Uganda and other countries supervised the grant selection and supervision. A total of 44 grants were awarded to multidisciplinary teams over three years, with 12 projects awarded in 2007, 15 in 2008, and 12 in 2009. These grants were given to postgraduate students at both master's (57 students) and PhD (31 students) levels, who were integrated into the projects. The overall progress of the MSI project

has been deemed satisfactory (Crawford et al., 2006; Guimón, 2013) with significant outcomes in terms of research, curriculum development, science outreach, and institutional strengthening.

Uganda's efforts to encourage innovation and commercialization are supported by various measures, such as political initiatives, international partnerships, infrastructural advancements (Nahikiriza, 2023), and cutting-edge financial technologies, such as crowdfunding (Ogwang & Vanclay, 2021). Despite facing challenges such as the need for stronger technology development and commercialization, Uganda is steadily creating a favorable environment for innovation. To ensure continuous progress, it is essential to continue formulating policies that promote innovation, encourage public-private partnerships, and utilize innovative financing methods while adhering to international standards and best practices.

### *Protecting intellectual property*

Uganda boasts a comprehensive legal framework for intellectual property, which encompasses the Patents Act, Copyright and Neighboring Rights Act, and Trademarks Act. These laws do not differentiate between IP ownership by individuals and organizations and allow for joint ownership. As a result, individual scientists in Uganda can claim sole ownership of IPRs unless stipulated otherwise in a contract with their employer, such as a university, or if the organization's bye-laws and policies indicate otherwise. However, many scientists and innovators in Uganda are unaware of existing IP laws, and numerous universities and research organizations, excluding Makerere University, lack effective internal policies for Intellectual Property (IP) management. Historically, Uganda has fallen behind other countries in terms of safeguarding its IP. According to data from the Global Innovation Index (GII) (Dutta et al., 2022), Uganda filed only 39 patents since 2000, significantly fewer than Kenya's 452 patents in South Africa's 22,040 patents. To tackle this issue, the UNCST and Uganda Registration Services Bureau (URSB) joined forces and launched IP seminars to raise IP

awareness among researchers, entrepreneurs, and scientists.

The importance of IP rights in fostering innovation and competitiveness has been recognized worldwide (Tahir et al., 2022). However, protecting IP in the digital age presents challenges for Uganda given the global nature of the Internet (Ma, 2020). Blockchain technology can be used for IP protection (Zinych, 2021) and innovative strategies employed by foreign firms in emerging economies with weak IP enforcement (Ziebermayr, 2021) can be considered for implementation in Uganda. Scholars have highlighted various aspects of IP protection including legal frameworks (Tahir et al., 2022), technological solutions (Zinych, 2021), and strategic management (Ziebermayr, 2021). These insights suggest that an integrated approach to IP protection incorporating legal, technological, and strategic elements may be effective.

The national IP policy (MOJCA, 2019) devised by the Ministry of Justice and Constitutional Affairs and the URSB focuses on Uganda's TRIPS obligations. This policy spurs innovation, safeguards intellectual property rights, and fosters creativity, all of which are vital components of a robust IP system. Although IP protection is crucial in an effective IP regime, it is not the only one. Innovators must also consider other strategic options, such as investment and licensing, as well as the structure and functions of the innovation system to optimize the value of their IP assets (Pererva et al., 2024).

Scholars have emphasized the complexity of enforcing intellectual property rights and stressed the need for a comprehensive strategy that integrates robust legal frameworks, innovative technologies, and strategic management practices (Ma, 2020; Zinych, 2021; Tahir et al., 2022). It is essential for Uganda to adapt these principles to its local context, taking into consideration the country's unique legal, economic, and technological environment, to effectively protect intellectual property rights.

## Method

### *Study design and approach*

Both qualitative and quantitative research methodologies were employed through data acquisition through interviews and observational techniques. Diverse forms of evidence were obtained through interviews and direct observations of the selected techno-business entrepreneurs. To ensure the dependability and credibility of the study, a rigorous procedure was followed, in accordance with Plotz (2020).

### *Study population*

A total of 55 techno-business entrepreneurs were selected based on purposive sampling to participate in the study. The inclusion criteria involved participants with a thorough understanding of the innovation and commercialization landscape in Uganda. The selected participants were actively involved in the innovation and commercialization processes within their firms and had a strong background in the firm's R&D activities. These individuals were chosen for their valuable insights and ability to provide detailed accounts of the commercialization process within their respective firms. This careful selection process ensured that the insights provided by participants were relevant and valuable.

### *Data collection*

The research project was initiated in 2023, during which the principal investigator was responsible for distributing questionnaires to the participants. Furthermore, online questionnaires were available to those who preferred to complete them independently. The data collected for this study were obtained through interviews and observations of innovation and commercialization patterns. Observations were conducted to understand the dynamics and contextual elements of techno-business enterprises. Interviews were held with techno-business entrepreneurs to gain insights into innovation and commercialization procedures within firms. This method allows researchers to examine real-life situations and gain a deeper understanding of firm-level innovation and commercialization. This approach

is highly relevant to empirical studies based on observations or experiences, as stated by Mihas (2019) and Lester et al. (2020).

### *Data analysis*

The questionnaires were thoroughly examined for completeness and consistency to ensure accuracy of the collected data. The data were then entered into Microsoft Excel, organized, and meticulously cleaned before analysis using the Statistical Package for Social Scientists (SPSS) 26.0.

A content analysis tool that involves the coding and categorization of qualitative data was utilized (Mihas, 2019; Lester et al., 2020). The researcher thoroughly read the documents and analyzed them to identify the factors, stakeholders, and contexts that drive innovation in the ecosystem. The results of each phase were combined and used to develop

the different codes. Next, the codes were collated and grouped by phase and themes were assigned to each code. Finally, the themes were summarized to produce the results of the study. To gain further insight into the innovation and commercialization processes within firms, an explanation-building procedure is employed in the cross-case analysis (Plotz, 2020). The synthesized data were then organized into chronologically arranged matrices, which were used to draw conclusions.

## **Results and Discussion**

### *Descriptive characteristics of the firms' innovation and commercialization processes*

This involved presenting a thorough overview of the firms' approach and execution of innovation and commercialization plans and strategies.

**Table 1: Descriptive characteristics of the firms' innovation and commercialization processes**

Firm interactions (n=55)	Percent (%)
<i>Activities relevant to the firms' innovation and commercialization efforts</i>	
Research and development	24.6
Engineering, design, and other creative works	6.9
Marketing and brand equity	13.7
Intellectual property protection	17.7
Employee training	16.5
Software and database development	4.8
Acquisition or lease of tangible assets	4.4
Innovation management	10.5
Others	0.8
<i>Funding sources for the firms' innovation and commercialization activities</i>	
Own funds (retained profits or income from asset disposal)	21.7
Transfers from affiliated firms (holding, subsidiary, or associated companies located in the domestic country or abroad)	4.3
Customer orders (procurement contracts from domestic or foreign governments or international organizations)	10.1
Shareholder loans	3.6
Debt funding from commercial loans	4.3
Loans from government	2.2
Loans from international organizations	2.9
Equity from private equity or venture capital firms	2.9
Grants or subsidies from domestic or foreign governments, NGOs, CSOs	43.5
Others	4.3
<i>Firm strategies to influence the markets for its products</i>	
Upgrade goods or services	10.9
Expand the range of goods or services	15.0
Create new markets	13.2
Enter new markets or adapt existing products to new markets	12.4
Increase or maintain market share	7.5
Increase the reputation, brand awareness, or visibility of goods or services	16.2
Comply with market regulations	11.7
Adopt standards and accreditation	12.8
Others	0.4

*Firms' innovation and commercialization activities*

The research adhered to Section 4.2, page 87 of the Oslo Manual (OECD/Eurostat, 2018) and analyzed the influence of innovation and commercialization efforts on product improvement, IP creation, market differentiation, new opportunity discovery, and collaboration facilitation. By investing in these initiatives, firms can enhance their competitive edge, promote growth, and achieve sustained market success (Avenyo et al., 2021; Hussen & Çokgezen, 2022).

Many firms reported that R&D is a critical aspect of their innovation and commercialization efforts, with 24.6% of respondents indicating this to be the case (Table 1). R&D is crucial for driving innovation within a firm by conducting systematic research, experimentation, and inventing new products, processes, and services (Crowley & McCann, 2018; Saka-Helmhout et al., 2020). R&D investment enables firms to remain competitive, adapt to market changes, and develop innovative solutions to meet customer needs.

This study found that approximately 18% of the surveyed firms granted exclusive rights to their ideas through IP-related activities. Firms can maintain a competitive advantage and generate revenue by protecting their ideas, technologies, and brand identity through IP protection (Rajapathirana & Hui, 2018; Kesselring et al., 2023). This research highlights the importance of investing in R&D and safeguarding IP rights to promote innovation and commercialization among businesses.

Approximately 16.5% of the firms surveyed engaged in collaborative staff training with academic institutions, research organizations, and other firms (Table 1). This collaboration can lead to knowledge exchange, access to specialized skills, and an expanded research scope (Abbas et al., 2018; Zhu et al., 2020). By joining forces, firms can reduce costs, share expertise, and accelerate the research and commercialization process.

This study reveals that a substantial proportion of firms (13.7%) invested in marketing and branding efforts to develop unique and differentiated products or services that satisfy customer needs and provide superior value. In doing so, businesses can attract more customers, build brand loyalty, and expand their market share.

The survey results show that many firms engaged in innovation management (10.5%), engineering design (6.9%), and software development (4.8%) to enhance their products, processes, and efficiency. Through continuous development, firms can identify areas for improvement and create new products or services to meet the changing market needs and improve their competitiveness (Barasa et al., 2017; Hussen & Çokgezen, 2022). Such activities are essential for firms to remain competitive and to offer better products and services. Continuous development is necessary to remain competitive and to offer better products and services.

The study indicated that only a small proportion (4.4%) of the firms engaged in acquiring or leasing tangible assets. These activities may lead to new market opportunities and offer various options. By exploring new technologies and emerging trends, firms may discover untapped or specialized markets, as per Crowley and McCann (2018) and Avenyo et al. (2021). Learning about customer preferences, behavior, and future demands through market research helps firms leverage emerging trends and expand their businesses.

*Funding sources for the firms' innovation and commercialization activities*

Funding is crucial for innovation and commercialization, as outlined in Section 4.4.4 of the Oslo Manual on page 98 (OECD/Eurostat, 2018). Financial support is necessary to turn theoretical concepts into practical and financially viable solutions that benefit the firm and its stakeholders, as emphasized by Kim et al. (2019) and Saka-Helmhout et al. (2020). According to a survey, 43.5% of firms' financing for innovation and commercialization comes from government

grants or subsidies, Non-Governmental Organisations (NGOs), and Civil Society Organisations (CSOs). Firms also use their own profits (21.7%) and client orders (10.1%) as funding sources. Adequate funding allows firms to invest in technology, conduct market research, and validate their innovations, enabling them to understand customer needs, discover market opportunities, and prove commercial viability.

*Firm strategies to influence the markets for its products*

Firms can differentiate their products through unique features, quality, and design, providing a competitive advantage and attracting customers who value these unique features (Saka-Helmhout et al., 2020; Kreiterling, 2023). Research shows that firms use various strategies to influence their product markets, such as enhancing their reputation, expanding their range of goods and services, creating new markets, and complying with market regulations (16.2, 15, 13.2, and 11.4%, respectively). However, increasing or retaining market share (7.5%) is considered the least effective strategy for influencing the market for a firm's products (Table 1).

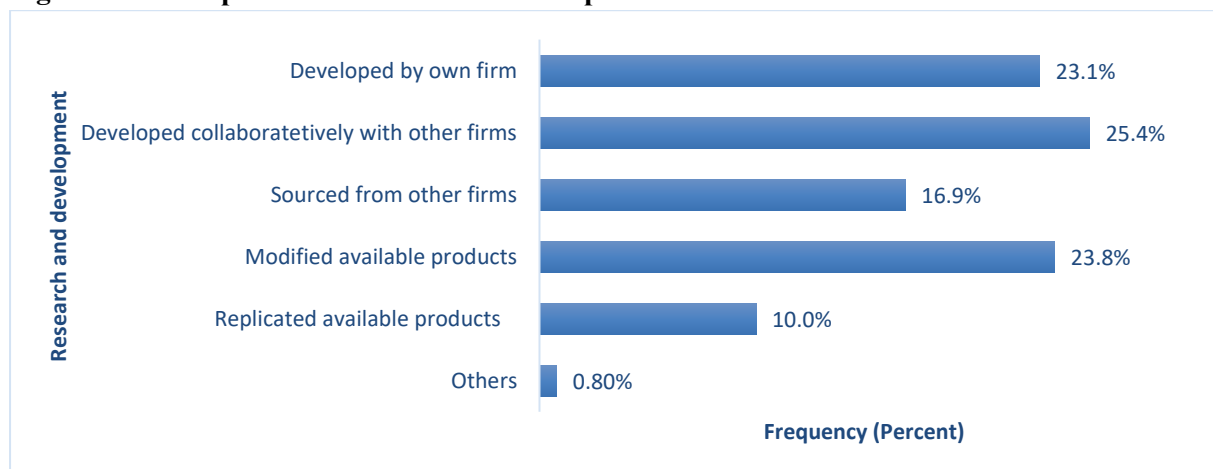
A firm can opt for a competitive or premium pricing strategy depending on factors such as manufacturing costs, target market, competition, and perceived value. Effective marketing and

advertising can boost brand recognition, drive product demand, and shape customer perception. Firms can utilize various channels, such as television, radio, print media, Internet advertising, social media, and influencer marketing to reach their target audience. Additionally, providing excellent customer service can significantly improve the overall customer experience, as reported by Zhu et al. (2020) and (Teixeira et al. (2021). This includes promptly responding to inquiries, effectively managing complaints, and offering personalized assistance.

*Firms' product or innovation development activities*

This study explores the influence of product innovation development on a company's competitive advantage, customer satisfaction, market expansion, revenue growth, brand image, market adaptation, and talent recruitment, as outlined in section 6.3.2 of the Oslo Manual (OECD/Eurostat, 2018). Allocating resources for product development and commercialization can help firms achieve long-term success in competitive markets (Rajapathirana & Hui, 2018; Saka-Helmhout et al., 2020). As Figure I shows, a significant number of firms reported creating products or innovations through collaborative agreements with other firms (25.4%), modifying existing products (23.8%), or modifying their initial ideas (23.1%).

**Figure I: Firms' product or innovation development activities**



According to Crowley and McCann (2018), and Hussen and Çokgezen (2022), developing

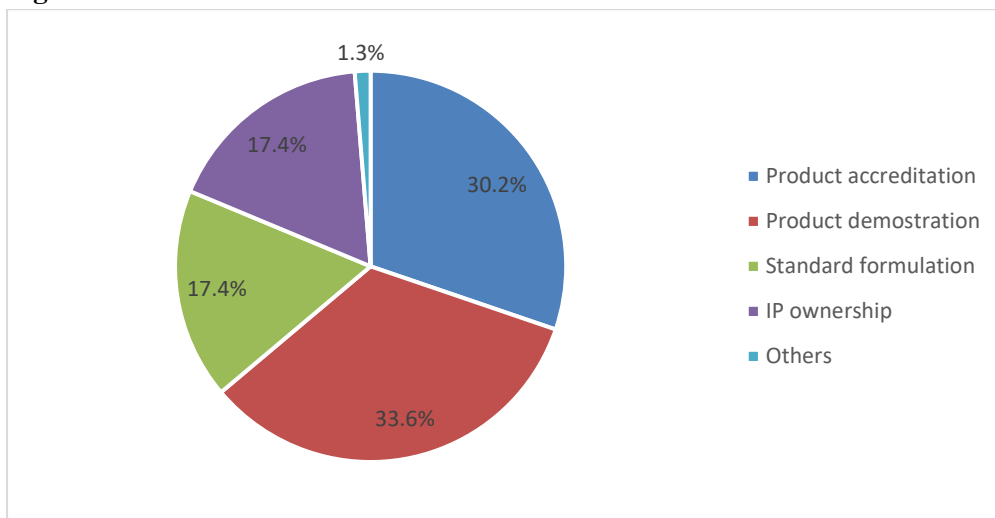
exceptional products can differentiate firms from competitors by providing a competitive edge that

aids in attracting and retaining clients, expanding the market share, and staying ahead of the market. Continuous improvement and innovation that meets or surpasses customer expectations and enhances customer satisfaction are essential. Firms can foster increased customer loyalty and repeat businesses through improved products and services by effectively addressing customer needs. The survey results indicate that firms face issues, such as product duplication (10%) and heavy reliance on external ideas, concepts, and information (16.9%). Product development innovation allows firms to explore new markets and customer segments by creating and commercializing new products.

This study examines the role of standards in aiding firms in effectively navigating markets, fostering innovation, improving interoperability, managing risks, and expanding their reach. Firms can increase their growth, competitiveness, collaboration within markets, and innovation activities by adhering to and actively participating in standardization efforts (Avenyo et al., 2021; Kreiterling, 2023). The survey results indicate that 33.6% of the participating firms found standards useful for demonstrating the quality of their goods or innovations, whereas 17.4% considered them necessary to promote the involvement of enterprises in developing industry standards and owning IP rights (Figure II).

*Role of standards in the firms' markets and innovation activities*

**Figure II: Role of standards in the firms' markets and innovation activities**

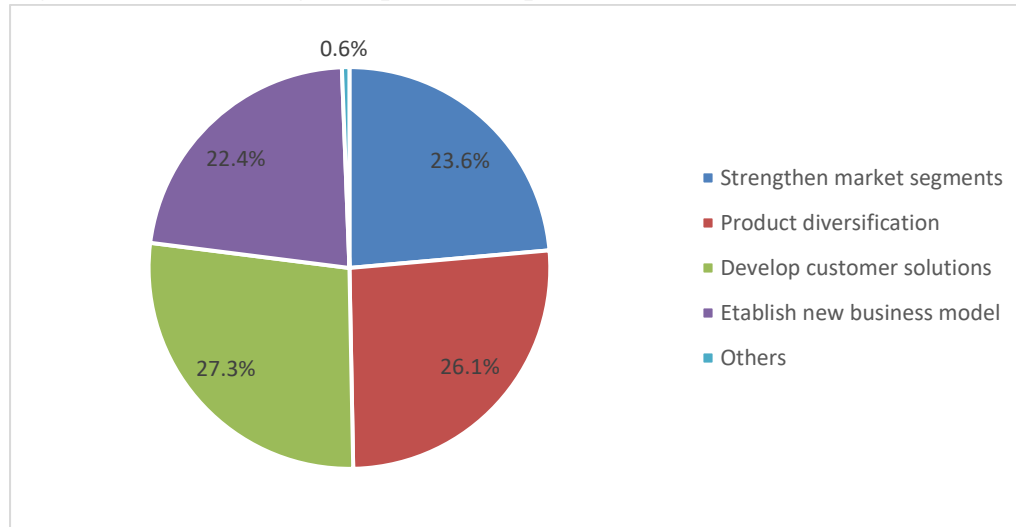


Standards are essential for businesses to efficiently market and innovate. They ensure that products, systems, and services work together and establish technological requirements and protocols that allow seamless integration between businesses. By fostering collaboration and reducing redundancy, standards promote innovation and help organizations focus their resources on creating new solutions instead of upgrading existing ones. This leads to faster time-to-market for new products and services.

Product positioning evaluates customer perceptions of a firm's offerings relative to its competitors, according to the OECD/Eurostat (2018). This involves highlighting the firm's beliefs, goals, and vision and demonstrating how its products or services address customer needs and enhance their lives. As shown in Figure III, firms employ various techniques to position their products in the market, such as tailoring solutions for specific customers (27.3%), diversifying or expanding product lines (26.1%), strengthening positioning in distinct market segments (23.6%), and developing new business models (22.4%).

*Firm strategies to position its products on the market*

**Figure III: Firm strategies to position its products on the market**

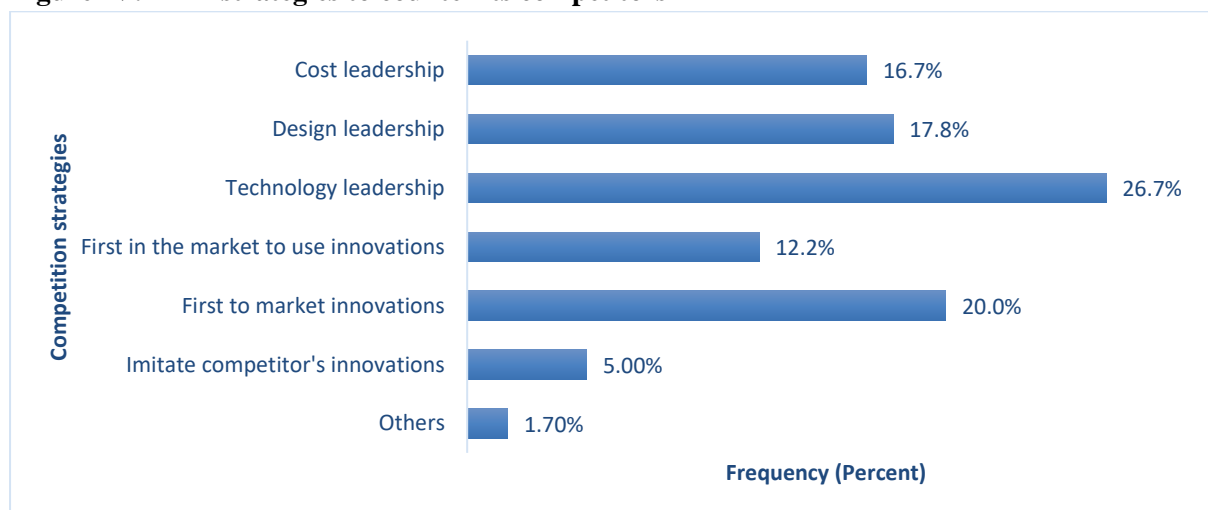


Effective product positioning depends on choosing the right strategy based on the target audience and the competition. A clear and concise marketing message that communicates positioning strategies is essential (Saka-Helmhout et al., 2020; Kreiterling, 2023). It is crucial to ensure consistency across all marketing materials including websites, packaging, and advertising. A combination of online and offline marketing methods, such as social media, websites, print media, television, trade exhibitions, and relationships with influencers and industry leaders, should be used to reach the target audience.

*Firm strategies to counter its competitors*

To effectively compete in a market, firms must understand their target audience and unique value propositions, as outlined in Section 8.2, of the Oslo Manual (OECD/Eurostat, 2018). This involves the identification of the target market, customer needs, and pain points. Firms can then develop a positioning strategy that aligns with their market's unique requirements by gaining insight into their customers. The survey revealed that firms use various strategies to compete, such as offering technological leadership (26.7%), first-to-market product or service innovation (20%), design leadership (17.8%), and cost leadership (16.7%). Replicating competitive ideas (5%) and being the first to adopt product advancement in the market (12.2%) were the least effective competitive strategies (Figure IV).

**Figure IV: Firm strategies to counter its competitors**



According to Hussen and Çokgezen (2020), and Avenyo et al. (2021), it is important to use case studies, testimonials, and certifications to demonstrate a firm's expertise, record achievements, and industry knowledge. Additionally, analyzing the strengths and weaknesses of competitors can help identify market gaps and differentiate a firm's products or services. Developing a unique value proposition and effective branding and marketing plans are essential for setting a firm apart from its competitors. This involves creating strong brand identity and consistently communicating key messages across all marketing channels.

### **Innovation and commercialization challenges encountered by techno-business firms**

To comprehend the difficulties that techno-business companies in Uganda are confronted with innovation and commercialization, it is crucial to consider the broader context of startup ecosystems in emerging markets and the challenges that technology-focused startups encounter. Although the resources provided do not specifically refer to the Ugandan context, they offer useful information regarding the common obstacles that can be applied to the Ugandan situation.

Techno-business firms especially those in the technology sector, often grapple with a lack of institutional support, which can impede their growth and hinder their ability to innovate (Bakhtiar et al., 2020; Maulana et al., 2022). Moreover, the rapid pace of technological change, unpredictable customer demand, and market profitability are crucial market contingencies that startups must navigate (Butnik-Siverskyi et al., 2024). These challenges are further compounded by the need for startups to collaborate with innovation ecosystems to support their technological and business model innovations, which may be underdeveloped in emerging markets such as Uganda.

Startup techno-business firms frequently face obstacles when attempting to monetize innovations, particularly when counting external entities within their innovation ecosystems to

navigate market uncertainties (Butnik-Siverskyi et al., 2024). In addition to establishing strategic alliances, techno-business enterprises must comprehend regulatory and ethical concerns and consistently adjust to technological advancements and market shifts to achieve success (Maulana et al., 2022).

Techno-business enterprises in Uganda are likely to face challenges, such as those encountered in other emerging markets, including inadequate institutional support, the complexity of navigating rapidly changing technological environments, and the need for developed innovation ecosystems. To overcome these obstacles, strategic planning, the development of innovation ecosystems, and a thorough understanding of the local context are necessary to facilitate the commercialization of technology and the sustainable growth of startups (Maulana et al., 2022; Butnik-Siverskyi et al., 2024; Pererva et al., 2024).

### **Recommended strategies for improving innovation and commercialization outcomes**

To successfully apply strategies to improve innovation and commercialization in techno-business firms in Uganda, it is essential to consider the results and outcomes of various studies focusing on innovation, commercialization, and business performance.

Techno-business firms must prioritize the development of efficient business models that facilitate the commercialization of innovative products, as doing so can greatly enhance their economic potential and value delivery (Kusumawati et al., 2022). Furthermore, the implementation of agile methods can improve the effectiveness of innovation processes, resulting in the prompt and successful commercialization of new technologies (Lages et al., 2023). In addition, it is crucial for corporations to formulate innovation strategies that encompass products, processes, markets, and technological innovation, as studies have shown that these factors positively influence firm performance (Kanyi & Kihara, 2022).

Moreover, devising technological catch-up strategies and government support programs may enhance a company's capacity for innovation in new product development, which is essential for businesses to remain competitive and meet market expectations (Mukhtar et al., 2021). Additionally, technology-driven business analytics can assist techno business firms in making well-informed decisions that promote growth and provide a competitive advantage (Kumar & Aithal, 2024).

Adopting ambidextrous innovation, which entails reconciling market-driven and driving-market business models, may result in improved organizational performance, as indicated by Kusumawati et al. (2022). Market orientation and innovation have been shown to have a positive relationship with business performance, and it is essential to consider the regulatory influence of the business environment when devising strategies (Giang, 2022). Techno-business enterprises must also adapt to the evolving marketing landscape, particularly the emergence of web-based marketing tactics (Mogull, 2021). Comprehending monetization processes in Internet marketing can assist organizations in transforming target audience behavior into revenue streams, which is crucial for small businesses (Mishra et al., 2024).

Uganda's techno-business enterprises should develop tailored business models, implement agile and innovative strategies, capitalize on government support for new product development, leverage business analytics, balance business model ambidexterity, maintain market orientation, adapt to evolving marketing strategies, and comprehend Internet marketing monetization processes to enhance innovation and commercialization. These strategies are underpinned by empirical evidence that demonstrates their positive impact on firm performance and commercialization (Kanyi & Kihara, 2022; Kusumawati et al., 2022; Lages et al., 2023; Kumar & Aithal, 2024).

## Conclusion

### Theoretical implications

The consequences of improved innovation and commercialization processes among techno-business enterprises in Uganda can be inferred from the broader context of innovation performance and business model effectiveness in various regions and industries. Research on Ugandan manufacturing companies suggests that although innovative firms, as indicated by computer usage and new machinery purchases, tend to grow faster on average, innovation does not necessarily lead to substantial differences in growth rates compared with non-innovative firms (Bowman, 2019; Onapa et al., 2018). This finding contrasts with the positive correlations between innovation performance and efficiency- and novelty-oriented business models observed in high-tech Chinese service companies (Jian & Hongxia, 2023).

Previous research has highlighted the importance of business models in managing commercialization and innovation in small technology companies (Maulana et al., 2022). These models serve as guides for operational-level commercialization. Therefore, it is crucial for techno-business companies in Uganda to adopt suitable business models for effective commercialization. Additionally, the initial stages of commercialization heavily depend on financing, as technology-based companies often rely on informal sources, such as venture capital, before receiving formal funding (Yin & Chang, 2021; Moon, 2022).

To enhance the innovation and commercialization processes for techno-business enterprises in Uganda, it is essential to adopt business models that are in sync with their innovation strategies and provide access to suitable financing options. Although it is important to exercise prudence when applying findings from other regions because of contextual differences, the general principles of business model innovation, funding strategies, and the role of technological innovation as a mediator (Yin & Chang, 2021;

Moon, 2022; Jian & Hongxia, 2023) can offer valuable insights for Ugandan firms.

### **Policy implications**

The effects of policy on fostering innovation and commercialization procedures for techno-business companies in Uganda should consider the current technological innovation situation based on scientific advancements, as well as the broader economic and innovation environment. Uganda has demonstrated a dedication to cultivating science, technology, and innovation (STI), as evidenced by initiatives such as MSI (Guimón, 2013). However, the country still lacks a coordinated mechanism for aligning STI policies among stakeholders, and technology development and commercialization remain underdeveloped.

Considering the negative impact of economic policy uncertainty (EPU) on green technological innovation among non-state-owned and low-tech businesses, as demonstrated by recent research (Zhou et al., 2024), it is crucial for Uganda's policies to focus on reducing EPU and fostering stable conditions that promote innovation. Moreover, the significance of appropriate business models for successful new product commercialization in small technology firms (Maulana et al., 2022) and the need for innovation support services tailored to the commercialization strategies of new technology-based firms (Butnik-Siverskyi et al., 2024) indicate that providing targeted support for business model development and innovation services could be advantageous.

Tax policies and development tax incentives have the potential to promote technology commercialization and foster innovative entrepreneurship, as indicated by Lages et al. (2023). Additionally, incubator policies that support entrepreneurial development and act as intermediaries between university research and industry can enhance the technology commercialization process (Fitria & Hakim, 2022). Consequently, Uganda should consider implementing similar tax incentives and incubator programs to stimulate the growth of its techno-business firms.

To improve the innovation and commercialization processes within techno-business firms in Uganda, it is crucial to focus on establishing a stable economic environment, offering targeted innovation support services, implementing tax incentives for R&D, and establishing effective incubator programs that bridge the gap between research and industry. These measures can foster an ecosystem conducive to the growth of techno-business firms and enhance Uganda's overall innovation capacity, as suggested in various studies (Fitria & Hakim, 2022; Maulana et al., 2022; Butnik-Siverskyi et al., 2024; Zhou et al., 2024).

### **Ideas for future research**

Future research on improving the innovation and commercialization processes of techno-business enterprises in Uganda may benefit from utilizing a multifaceted strategy. Studies have explored the role of knowledge-generating institutions in manufacturing firms' innovation practices, particularly in the food, beverage, chemical, and pharmaceutical sectors (Ecuru et al., 2014). Further research could investigate the obstacles to collaboration and develop frameworks for effective engagement between academia and industry, thus fostering a culture of innovation and trust.

Investigating the harmonization of STI stakeholders in the technology industry and the processes by which they can be improved to foster the development of technological innovations based on scientific research is crucial (Kapiriri et al., 2020). Furthermore, research could examine the impact of initiatives such as MSI on entrepreneurship and industry-academia collaboration.

Research should concentrate on assessing the business models utilized by small technology firms for product launches to identify effective strategies and enhance innovation management (Maulana et al., 2022). Additionally, innovation culture and customer co-creation influence market success in Information and Communication Technology (ICT) companies that provide

knowledge intensive business services (Alpraeska, 2022).

Research could delve into the technological catch-up strategies used by governments in emerging economies to develop new product development capabilities within local small and medium-sized enterprises (SMEs) (Mukhtar et al., 2021). It is also crucial to investigate the impact of economic policy uncertainty (EPU) on business development and innovation, with a focus on green technological innovation (Zhou et al., 2024).

Future research could explore alternative financing methods for technology-based businesses, particularly during the initial stages of technology financing, and how this impacts commercialization (Yin & Chang, 2021; Moon, 2022). Additionally, it could examine the development of effective innovation funding mechanisms, particularly in challenging situations, such as martial law (Zaburanna & Yarmolenko, 2022).

Research can assess the external factors that accelerate the growth of innovative startups and technology-based companies with an emphasis on macroeconomic stability and human capital (Jurgelevičius & Kučaidze, 2020). Furthermore, this study investigates the influence of technology-driven business analytics on the quaternary sector and its impact on market trends, consumer behavior, and operational performance (Kumar & Aithal, 2024).

Future research should focus on connecting academia and industry, enhancing the coordination of STI policies, evaluating effective commercialization business models, assessing the influence of government strategies and economic policy uncertainty on innovation, examining financing mechanisms, and exploring the impact of business analytics on innovation. These studies have the potential to offer valuable insights that can strengthen the innovation capabilities and commercialization success of techno-business firms in Uganda (Kapiriri et al., 2020; Alpraeska, 2022; Kumar & Aithal, 2024; Zhou et al., 2024).

### Limitations of the study

This study discusses the contributions of techno-business firms to the innovation and commercialization landscape in Uganda. However, a comprehensive analysis of innovation and commercialization requires consideration of a broader innovation ecosystem, including educational and research institutions, examining the specific barriers that impede commercialization and affect business models, and evaluating the influence of absorptive capacity on innovation outcomes.

### Declarations

**Data availability statement:** The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

**Disclosure statement:** The authors declare no conflicts of interest.

**Author contributions:** All authors contributed to the writing of the manuscript and read and approved the final manuscript.

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## **PAPER III**



## Contribution of R&D grants and investment to the commercialization of innovations in Uganda: Lessons from UNCST a science granting council

Ronald Jjagwe, John Baptist Kirabira & Norbert Mukasa

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## Contribution of R&D grants and investment to the commercialization of innovations in Uganda: Lessons from UNCST a science granting council

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The Government of Uganda (GoU) has prioritized Science, Technology, and Innovation (STI) in its pursuit of a knowledge-based economy. While scholars have identified a positive association between innovation investment and performance, the role of R&D grants and investment in the commercialization of innovations and their influence on innovation performance require further clarification. The objective of this study is to examine the contribution of R&D funding and investment to the commercialization of innovations in Uganda. A qualitative research method was employed using case study and interview approaches. This method involves gathering various types of evidence including document reviews, field visits, and interviews with key informants and focus groups. Data analysis was conducted by matching themes derived from document reviews, case studies, and interviews. The study findings highlight the need for GoU to prioritize institutional development, address structural problems to innovation input, promote talent flow, and rationally build regional knowledge value chains to improve innovation and commercialization efficiency. The Uganda National Council for Science and Technology (UNCST) must maintain momentum in gathering STI indicators to support the evidence-based formulation of effective STI policies. This study provides theoretical and policy-oriented insights by emphasizing the significance of R&D funding and investment in facilitating the commercialization of innovations in Uganda.

**Keywords:** commercialization, innovation, R&D grants, R&D investment, Uganda

### Introduction

The interdependence between science, technology, and innovation (STI), economic growth, and social transformation has been widely recognized as an essential factor in economic development (Aktar, Harun, and Alam 2021; OECD 2021; Perry 2020). Recent research has demonstrated a direct link between STI advancements and the progress and transformation of countries from agricultural to knowledge-based economies. The degree to which a country embraces and harnesses STI directly correlates with its level of development. Considering the global recognition of the importance of STI in the development process, nations have established national innovation systems (NIS) to closely link STI to economic systems, as highlighted by Chaminade, Lundvall, and Haneef (2018) and Kurpayanidi (2021). These systems consist of a network of institutions that work together to generate and consume knowledge and technology and encourage collaborative efforts among institutions to develop and implement innovative products, processes, and organizational practices.

The STI system consists of universities, research and development (R&D) institutes, private firms, financial institutions such as commercial banks, technology support agencies, policy-making organizations, and the government. According to Aktar, Harun, and Alam (2021), understanding the intricate relationships between these institutional players is crucial for improving a country's technical and economic performance. The NIS aims to create new knowledge, develop human capital, promote, and disseminate technical opportunities, produce, and distribute goods, ease regulations for technologies, materials, and products, legitimize technology

and enterprises, and enhance networking, among other objectives.

The international competition landscape has progressively transformed into a contest for scientific and technical expertise, as highlighted in Schwab and Zahidi (2020). Concurrently, Uganda's domestic economic growth has transitioned from investment – and factor-driven development to innovation-driven development. The Government of Uganda (GoU) has consistently increased its investment in research, technology, and innovation. According to data from the Uganda Bureau of Statistics (UBOS), the number of full-time equivalent R&D staff has increased by approximately 3000 individuals annually over the past five years. In 2009, total R&D expenditure was 0.41% of the gross domestic product (GDP), which increased slightly from 0.37% in 2002 (UBOS 2020; UNCST 2016a, 2016b). During the same period, the GoU's grants increased from Uganda shillings (Ushs) 183.3 billion to 301.32 billion. As predicted by the National Development Plan (NDP) III, the overall societal expenditure on R&D is expected to reach 1% of GDP by 2030 (NPA 2020; Sithole 2020).

Numerous studies have demonstrated the existence of externalities in technological innovation in Uganda (Ecuru, Lating, and Trojer 2014; Fashina et al. 2019; Kwesiga 2019; Mulumba et al. 2017). The dissemination of information and technology (IT), as well as the likelihood of competitors imitating these advancements, inevitably has a significant impact on inventors' innovation excitement and is detrimental to the overall progress of technological innovation. Therefore, governments must implement incentives to encourage innovation and enhance technological R&D. For example, the

government subsidizes R&D and provides tax relief through grants. However, these subsidizing strategies do not yield desired outcomes. According to Wright, Siegel, and Mustar (2017) and Zhu, Zhao, and Abbas (2020), the reasons for this failure include beneficiaries' preferences for government R&D funding, the phenomenon of rent-seeking, and fraudulent practices of R&D subsidy recipients. Thus, enhancing R&D funds' effectiveness remains a challenge. Therefore, it is crucial to analyze government subsidies and their mechanisms of influence on innovation to boost national and firm innovation and provide government subsidies more effectively.

Drawing from the Uganda National Council for Science and Technology (UNCST) grant management practices and experience, this study examines the contribution of R&D funding and investment to the commercialization of innovations in Uganda. The UNCST is a GoU agency established by the Act of Parliament (CAP 209, Laws of Uganda), mandated to incorporate STI into the national development process (GoU 1990). The mandate of UNCST is STI grants management, R&D registration and oversight, STI policy implementation, STI promotion, and STI system monitoring. The UNCST funded research and development (R&D) and worked across local, regional, and global networks to elevate the STI in the national development debate (Brar et al. 2010; UNCST 2016a, 2016b). This study evaluates the potential of R&D grants and investments to enhance a country's ability to provide high-quality inventions and institutional commercialization initiatives. Based on the study findings, it is recommended that the GoU prioritize institutional development, address structural problems in innovation input, promote talent flow, and rationally build regional knowledge chains to improve innovation and commercialization efficiency. The study contributes to the empirical theory or explanation regarding the contribution of R&D grants and investment to the commercialization of innovations in Uganda, drawing from UNCST experiences.

The following sections discuss the literature review, research methodology, study findings and discussion, STI system performance indicators, R&D grants and investment impact analysis in key sectors, recommended interventions and key lessons learned, and conclusions.

## Literature review

### *Historical context*

During the colonial era, East Africa was home to several scientific institutions. Among these are the Virus Research Institute (VRI) in Entebbe and the Trypanosomiasis Research Organization (TRO) in Tororo, both of which are in Uganda. After achieving independence from Britain in the early 1960s, Kenya, Tanzania, and Uganda formed the East African Community (EAC), as highlighted in EAC (2015). The East African Medical Research Council (EAMRC) was established and oversaw scientific institutions with administrative headquarters in Arusha, Tanzania. The institutions set research priorities approved by the EAMRC. Although the institutions were required to submit their findings to the

EAMRC, there was no direct relationship between the research institutes and the health ministries. This has resulted in a prolonged period for research findings to reach the health managers in these countries.

According to EAC Vision 2050 (EAC 2015), research institutions that were part of the EAC returned to their respective countries after the EAC ceased to exist in 1977. In Uganda, VRI and TRO were transferred to the Ministry of Health. Nevertheless, the Ugandan government recognized the need to establish a national research organization before the EAC's demise and, in 1970, the National Research Council (NRC) was founded. The NRC comprises six committees, including those that focus on medical and veterinary research. Despite being a department of the Ministry of Planning and Economic Development (MPED), the NRC had limited authority as a non-legislative body and did not assume control of the EAC's research institutions upon its dissolution.

At that time, the NRC was tasked with determining research priorities, most of which focused on health and clinical matters. Additionally, structural, personnel, and budgetary concerns have hindered NRC's ability to effectively coordinate these priorities. For example, while the medical and veterinary committees held regular meetings and accepted research proposals, they were disorganized and not aligned with the needs of policymakers and health managers. Most research funding came from external sources, rather than from Uganda. In 1990, the NRC was rebranded the UNCST, an autonomous institution established by the Act of Parliament of Uganda. The UNCST facilitated and coordinated the development and implementation of policies and strategies for incorporating Science and Technology (S&T) into Uganda's national development process, as highlighted in GoU (1990).

### *Uganda's national innovation system*

During the 1990s, Uganda experienced notable economic growth and stability despite being one of the world's least developed countries. A World Bank evaluation indicated that, although the country's NIS has made substantial progress since 2000, it is still in its initial stages of development (World Bank 2021). According to Mulumba et al. (2017) and NPA (2020), NIS is limited in scale and lacks the necessary critical mass, which hinders its ability to achieve measurable outcomes. The annual investment in STI is estimated to be \$50 million, with approximately 800 researchers engaged in R&D, primarily at public institutions and R&D facilities in the country (UNCST 2016a, 2016b).

The scientific and engineering courses offered at the six universities in Uganda represent a significant portion of the country's higher education landscape. However, enrolment in basic science courses represents less than one percent of total secondary school enrolment (NPA 2020; UBOS 2020). Currently, only 558 university professors in Uganda hold doctorate degrees in all academic fields. The number of new doctorates conferred each year in science and engineering is relatively low, with less than ten awarded annually. The total R&D expenditure in 2009 was 0.41% of the GDP, which represents a slight increase

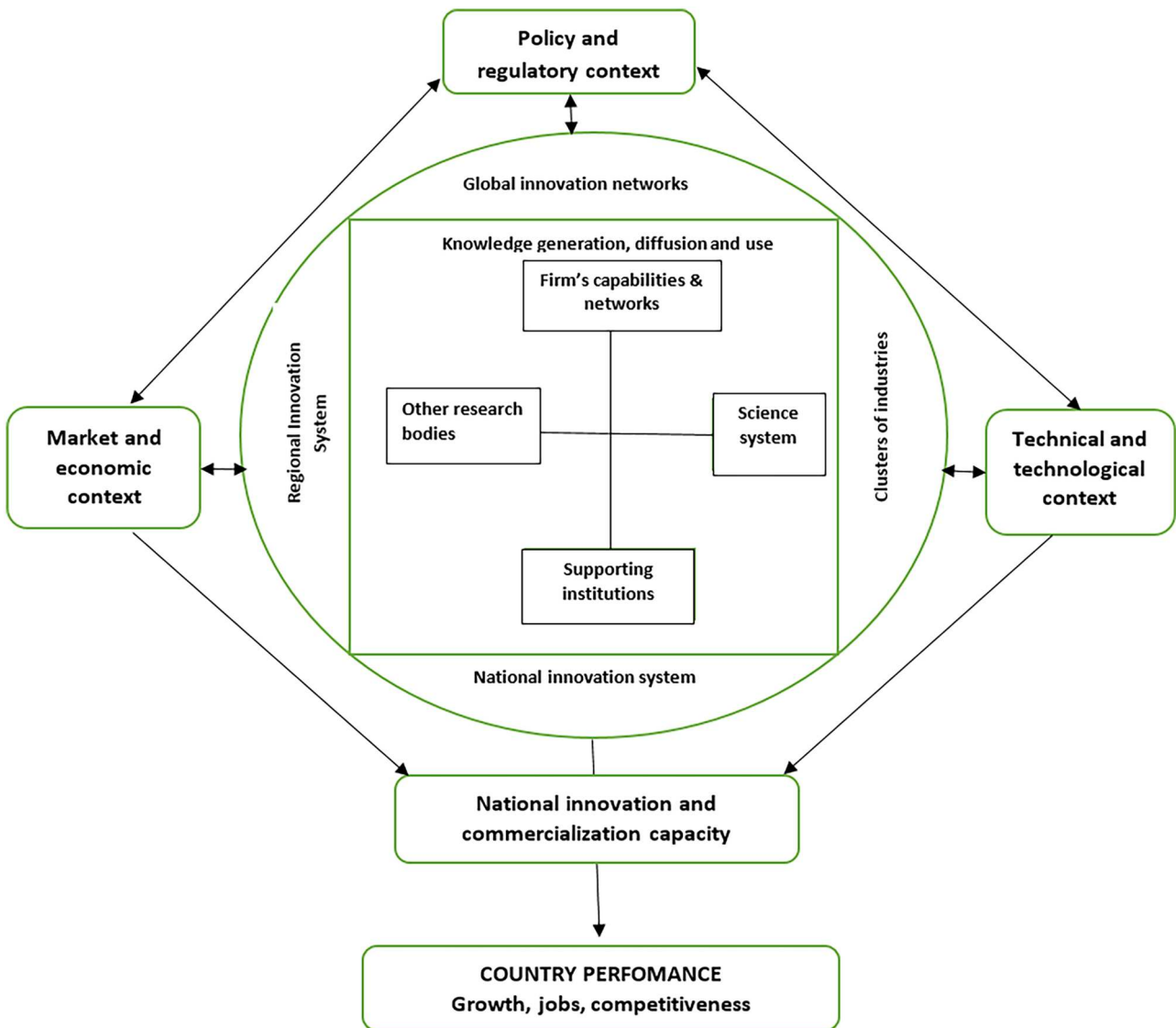
from 0.37% in 2002. Most of this R&D expenditure was conducted by the public sector and was funded by overseas donors. The private sector’s involvement in R&D is limited, with most private sector enterprises conducting R&D as foreign direct investment (FDI) (UNCST 2016a, 2016b).

Uganda’s NIS comprises research councils, public and private research institutions, private enterprises, universities, and related institutions that provide essential knowledge and skills (Figure 1). Additionally, there are other public and private organizations contribute to the NIS, such as public laboratories, technology transfer organizations, joint research institutes, training organizations, local governments, non-governmental organizations (NGOs), community-based organizations (CBOs), development partners, and consumers (Chaminade, Lundvall, and Haneef 2018; OECD 1999). The flow of knowledge and resources among these stakeholders determines the linkages within the NIS, which in turn reflects the system’s capacity for absorption. NDP III for fiscal years 2019/20–2024/25 of Uganda serves as the third in

a series of five development plans intended to guide the realization of Vision 2040, which envisions the transformation of Uganda from an agricultural-based economy to a knowledge-driven, middle-income country (NPA 2007, 2020). Despite the growing prominence and significance of STI in development, several challenges within the NIS have impeded the effective integration of STI into national development objectives.

**Coordination of the STI ecosystem**

Science-granting councils and organizations with similar objectives, including national commissions for science and technology, national science councils, and national academies of science, are essential stakeholders in STI coordination (Brar et al. 2010; Hanlin, Tigabu, and Sheikheldin 2020; Mouton 2018). These councils play several vital roles in well-defined systems of innovation and contribute to their successful and efficient operations. Recognized as expert entities by the global system of science governance, which is overseen by the Organization for Economic Cooperation and Development (OECD) and



**Figure 1:** National innovation system. *Source:* Chaminade, Lundvall, and Haneef (2018); OECD (1999) with modifications.

the United Nations (UN), scientific councils can generate competent judgments regarding various STI elements (OECD 2021). This recognition has facilitated the establishment of science councils in 136 countries worldwide, all under the auspices of the Global Research Council (GRC) in the United Kingdom.

According to Hanlin, Tigabu, and Sheikheldin (2020) and Sadeski et al. (2023), science councils in sub-Saharan Africa (SSA) typically focus on three key primary missions of a science granting council: (a) research granting, which involves providing funding to the scientific community through various means. Many agencies invite applications, manage peer-review processes, and award funds based on their merits and other relevant criteria. (b) Disbursements in scholarships and loans: Supporting postgraduate students is a traditional function of most science-granting councils. (c) Support for infrastructure development: Some science-granting councils provide funding for infrastructure development that is essential for advancing scientific research.

Sadeski et al. (2023) findings on the status and nature of science-granting councils in 17 sub-Saharan African countries indicate that these entities are at various stages of development. Some councils, such as those in South Africa, Tanzania, Kenya, and Zimbabwe, are well-established. However, others, such as those in Namibia, Botswana, and Mozambique are still in their initial stages. Francophone countries such as Burkina Faso, Senegal, and Cameroon, have diverse institutional frameworks, with competitive financing and related practices being relatively recent and less well-established. In many countries, the national environment is characterized by a multitude of financing bodies, programmes, and instruments, often organized around sectoral concerns such as health and agriculture.

### ***R&D granting, investment, and commercialization of innovations***

For an extended period, the objectives of innovation stakeholders have been to improve the efficacy of government investment in the field of STI and to enhance the capacity for scientific and technical innovation. According to Zhu, Zhao, and Abbas (2020), a firm's R&D activities primarily involve the generation of new knowledge and development of new products. Through investment in continuous R&D, firms may acquire items and technology related to innovation promotion and accumulate the capability for sustained innovation through learning. Additionally, R&D investment can facilitate the distribution of production factors among different innovators, promote the formation of innovation alliances, broaden the scope of the use of innovative resources through open innovation, expand the dissemination and diffusion of innovative products and ideas, and ultimately improve innovation efficiency (Hussen and Çokgezen 2021; Zhu, Zhao, and Abbas 2020).

According to Barasa et al. (2017) and Avenyo, Konte, and Mohnen (2021), innovators may not be fully able to take advantage of all the benefits of innovative activities and the personal rewards they receive may be less than the benefits to society. Subsidies and indirect grants are

often necessary to boost innovators' personal benefits. Numerous studies have explored the connections between government grants and innovation performance, revealing that government grants are an important factor that directly influences innovation players' initiatives, ultimately impacting innovation and commercialization efficiency (Hussen and Çokgezen 2021; Saka-Helmhout, Chappin, and Vermeulen 2020; Zhu, Zhao, and Abbas 2020). The government can encourage high-tech corporations to invest in R&D and produce innovative results by providing R&D funding.

Based on the literature reviewed, we propose the following hypothesis: Government R&D grants and investments have an impact on the commercialization of innovations in Uganda.

## **Method**

### ***Study design and approach***

A qualitative research method was employed using case study and interview approaches. This method involves gathering various types of evidence including document reviews, field visits, observations, and interviews with key informants and focus groups. This is because of the diversity of UNCST stakeholders and the context-specific nature of the innovation and commercialization ecosystem. Case studies were conducted to understand the national R&D grants and investments implemented by UNCST and illustrate the magnitude and significance of the outcomes achieved through the impact of R&D granting and investment. Interviews were conducted to assess the impact of R&D grants and investments on the commercialization of innovations and provide alternative perspectives and explanations for the observed commercialization patterns.

### ***Study population***

Primary data for this study were collected through site visits to various project locations, during which key informant interviews were conducted. The study team conducted comprehensive interviews with project beneficiaries, UNCST staff, and other technical experts from the STI sector ministries, departments, and agencies (MDAs). The consolidation and triangulation of information from these diverse sources and approaches provided the necessary context and enabled a more in-depth investigation of the role of R&D funding and investment in the commercialization of innovations in Uganda.

### ***Data collection***

#### ***Document review***

A thorough examination of documents regarding the UNCST was conducted. This entailed an in-depth analysis of STI policy frameworks, such as the UNCST Act, sector plans, and policies, including the national STI Policy, 2009 (GoU 1990; MFPED 2009, 2012; NPA 2007, 2020). Other documents that were assessed included UNCST strategic plans, UNCST performance monitoring reports, annual reports, quarterly work plans and reports, project information documents for the Millennium Science Initiative (MSI), government support to scientists

(GSS), and the National Science Technology and Innovation Programme (NSTIP). Work plans, project implementation plans (PIPs) for key projects, implementing partner arrangements and budgets, quarterly progress reports, financial reports, relevant correspondence, and field reports were also reviewed. These documents provided administrative and survey data that facilitated qualitative impact analyses across key sectors.

#### Structured interviews

Key informant interviews (KIIs) were conducted with the current and former senior management teams of the UNCST, partners of the UNCST, members of the STI working group, representatives from various government MDAs, the Uganda Industrial Research Institute (UIRI), and other stakeholders in the STI sector. Additionally, former members of the UNCST Governing Council, programme managers, committee chairpersons, heads of divisions and units, and grant beneficiaries across UNCST funding platforms were interviewed. Focus group discussions (FGDs) were held with stakeholders, researchers, and notable scientists to gather information on R&D funding and investment, contributions, problems, constraints, goals, and prospects. The FGDs provided alternative perspectives and explanations for the observed commercialization patterns, underlying reasons, and contextual imperatives, which complemented the qualitative study.

#### Case studies

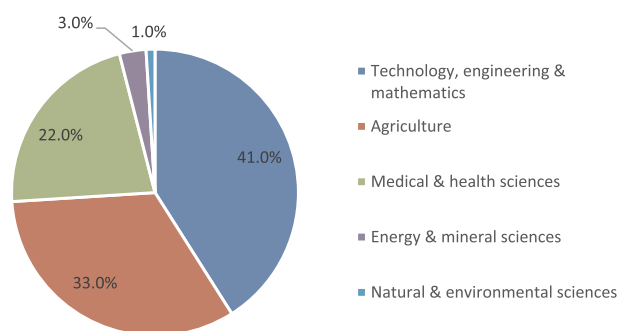
Case studies of different R&D grant interventions were employed to illustrate the magnitude and significance of the outcomes achieved through R&D grants and investments. These case studies were analyzed on a case-by-case basis (Plotz 2020) using a structured framework that included context and reasoning, objectives, outcomes, lessons learned, and critical recommendations. This framework was used to create testimonials, impact maps, and narratives of the impact pathways. The following criteria were used to identify the selected case studies: (a) the intervention's budget size, with a threshold of \$500,000 reaching UNCST; (b) the intervention's geographic coverage; (c) the availability of records within the institution; and (d) the long-term outcomes, which ranged from 1 to 3 years.

#### Field visits

Undertakings were made to visit sites that received support from UNCST through various financing agreements. These visits were conducted at MSI, GSS, and NSTIP project sites at both private and public universities, research institutions, and techno-business firms. Additionally, these trips were expanded to include demonstration farms and gardens, laboratories, and other infrastructure developed by UNCST's financing platforms.

#### Data analysis

Data analysis was conducted by matching themes derived from document reviews, case studies, and interviews (Mihás 2019). Relevant data and literature were used to provide the context and supplement interviews. A



**Figure 2:** UNCST-funded projects by area of national priority. **Source:** UNCST (2016b).

portion of the interviews was recorded, while the remainder was not. In cases where recording was not feasible or preferred by the interviewees, comprehensive notes were taken, and interview notes were prepared. All interviewees agreed to speak with the interviewers regarding anonymity and confidentiality.

The analysis of the generated data was conducted using a three-pronged approach (Lester, Cho, and Lochmiller 2020) and comprised the following three main phases: (i) data reduction, which involved selecting, clustering, abstracting, and transforming the documented transcriptions (interview data) into a usable and manageable form, and (ii) data display, which involved organizing the data in a manner that would facilitate the drawing of conclusions. The data were organized into time-ordered matrices and supplemented with information on their roles and inputs. (iii) Drawing conclusions and verification: This phase involved evaluating the key results of the study and, in some cases, re-analyzing the data to verify the findings.

## Findings and discussion

### Funding for research and development (R&D) in Uganda

The funding provided by the UNCST for R&D is directed towards national priorities. As shown in Figure 2, most of the funding (41%) was allocated to technology, engineering, and mathematics, followed by agriculture (33%), and health sciences (22%). As a result of this support, the capacity of Ugandan researchers has been strengthened. According to the UNCST (2016b), the percentage of researchers publishing in internationally referred journals increased from 1.7% to 11.9% in 2007 and 2012, respectively. Additionally, the percentage of researchers publishing in nationally referred journals and non-referred/non-academic journals increased from 2.0% to 14.7% and from 2.2% to 12.6%, respectively, during the same period.

Funding for scientific and technological initiatives is crucial to the development of any country. According to the UNCST (2016b), such initiatives have been acknowledged and supported by directly funding scientists and science education, aiding the establishment of scientific infrastructure in various research institutions and universities, and providing support for scientific and technical education and training. Notably, over half of UNCST's grants have been allocated to activities related to higher

**Table 1:** Selected national R&D grants and investment projects at UNCST.

R&D grant and investment projects	Implementation period	Partners	Impact areas
Millennium Science Initiative (MSI)	2007–2013	World Bank, GoU	Research infrastructure and human capital capacity development
Government Support to Scientists (GSS) Initiative	2005–2014	GoU	Scientific innovations and products in malaria control, banana value addition, ICT, and material science
National Science, Technology, and Innovation Programme (NSTIP)	2015–2016	GoU	R&D products for commercialization and industrial application
Innovation Fund	2017–2018	GoU	Generating and applying new knowledge to development challenges
Science Granting Councils Initiative (SGCI) in sub-Saharan Africa	2014–to date	IDRC, DFID, NRF, SIDA	Policy analysis, M&E, grants management, partnerships/collaborations, collaborative research grants
Eastern Africa Regional Research Network for Biotechnology, Biosafety, and Biotechnology Policy Development (BIO-EARN)	1999–2005	SIDA, GoU	Develop capacity and competencies to use effectively and integrate modern biotechnology
Coordination and Advancement of sub-Saharan Africa-EU Science & Technology Cooperation Network (CAAST-NET)	2014–2020	EU, GoU	Advancement of STI cooperation in research and innovation
Bio-resource Innovations Network for Eastern Africa Development (Bio-Innovate)	2010–2014	SIDA, GoU	Initiation, intensification, and dissemination of innovations for sustainable utilization, transformation, and integration
Development Research Uptake in sub-Saharan Africa (DRUSSA)	2012–2015	DFID	Capacity building in evidence-based policymaking

education and training leading to university degrees, post-graduates, and further training for scientists and engineers, to achieve a critical mass of scientists and engineers necessary for Uganda's development.

Health, engineering, and agriculture were the primary recipients of funding for STI in Uganda (UNCST 2016b). Although research in these traditional sectors (health and agriculture) has historically been the focus, it is anticipated that a diverse range of emerging fields will soon receive attention. To ensure the effective allocation of resources, it is essential to cultivate the expertise of researchers and funders in areas beyond traditional sectors. Moreover, new international funders may play a prominent role in shaping the future of STI funding and in exerting their influence. It is prudent to engage these actors early in the process to understand their interests and plans. Exploring avenues to develop capacity and create research initiatives that are relevant and applicable across multiple sectors is crucial to foster cross-sectoral collaboration.

#### ***National R&D granting and investment initiatives***

The UNCST Act establishes a Science and Technology Fund that serves as a legal framework for managing R&D funds (GoU 1990). The UNCST effectively managed the MSI funding facility, an initiative co-funded by the World Bank and the GoU (Crawford et al. 2006), as well as its successor, the NSTIP grant facility, following global best practices in grant management. The UNCST has also co-designed and is implementing a continent-wide competitive research grant programme within the framework of the Science Granting Councils Initiative (SGCI) in SSA with the support of Canadian, British, Swedish, German, and South African donor consortia (Sadeski et al. 2023). Other development partners, such as the European Union, Third World Academy of

Sciences (TWAS), and International Foundation for Science (IFS), have also managed their research grants through the UNCST Research Management Facility (Table 1).

Consequently, the UNCST is well-positioned to manage national research grants and leverage donor support to address national STI development priorities per Agenda 2030 (United Nations 2016), having successfully implemented MSI, GSS, and NSTIP, along with several international granting schemes aimed at strengthening national research and innovation capacity.

#### ***Millennium science initiative (MSI) Uganda***

MSI, a joint endeavour co-financed by the World Bank and the GoU, played a prominent role in fostering scientific innovation among local scientists and entrepreneurs from 2007 to 2013, as highlighted in Crawford et al. (2006). The initiative advocated for scientific advancement through competitive funding for basic, applied, and developmental research. The initiative supported the development of science and engineering university curricula, as well as the establishment of technology platforms to encourage collaboration between universities and the private sector.

According to Crawford et al. (2006) and Guimón (2013), MSI supported several R&D projects, enhanced the institutional capacity of the UNCST to effectively execute its mandate, and strengthened the capacity of the UIRI by rehabilitating and equipping its facilities (Table 2). As a result, the UIRI is now well-equipped to support techno-business firms and local communities with technologies, product development, resource data on the industry in Uganda, prototyping, small-scale production, and incubation (Crawford et al. 2006; Guimón 2013).

MSI is a pioneering initiative that has significantly advanced the development of STI in Uganda and East

**Table 2:** Key MSI project outputs.

MSI intervention area	Project outputs
Funding support to R&D projects	<ul style="list-style-type: none"> <li>(a) Training of 3660 scientists and engineers, with 57 at masters and 31 PhD levels</li> <li>(b) Development of a malaria vaccine candidate that progressed to clinical trials</li> <li>(c) Development of cassava variants with resistance to cassava brown streak disease</li> <li>(d) Propagation of catfish and the Nile perch under cultivation conditions to support the fish farming industry</li> <li>(e) Development of new techniques for assessing climate variability, environmental degradation, and lake level dynamics of Lake Victoria</li> <li>(f) Initiation of four new undergraduate courses in science, technology, and engineering (STE) and the upgrading of seven STE courses, these include; (i) Surveying and Land Economics at Makerere University, (ii) Biosystems Engineering at Gulu University, (iii) Pharmaceutical Sciences at Mbarara University of Science and Technology, (iv) Science Teacher Training programs at Kabale University, (v) Biotechnology at Makerere University, (vi) E-education Program at Kyambogo University, and (vii) Textile Engineering at Busitema University.</li> <li>(g) Development of molasses urea blocks to improve milk and meat production in livestock</li> </ul>
Institutional capacity enhancement of UNCST	<ul style="list-style-type: none"> <li>(a) Construction of new UNCST offices in Ntinda</li> <li>(b) Training of 45 UNCST staff members in various aspects of research and grant management</li> <li>(c) Enhancement of UNCST's capacity for evidence-based STI policy development, analysis, and advice</li> <li>(d) Enhancement of UNCST's capacity to collect policy-relevant data on the STI system</li> <li>(e) Facilitation of the formulation and government adoption of the National Biotechnology Policy (2008) and National STI Policy (2009) through the increased policy-relevant evidence base in the STI sector</li> <li>(f) Recognition of UNCST as a key driver of Uganda's STI system through its increased participation in global STI cooperation programmes</li> </ul>
Rehabilitation and equipping of UIRI	<ul style="list-style-type: none"> <li>(a) Mechanical engineering department, including basic computer-aided design and manufacturing services</li> <li>(b) Industry resource centre, industrial equipment and machinery that provide practically oriented training for technicians</li> <li>(c) Technology development centre, which now produces food-grade enzymes, electronics, and renewable energy system products</li> <li>(d) Vaccine plant, microbiology, and chemistry laboratory</li> <li>(e) Business development centre and pilot plants with an average of 30 projects under incubation</li> </ul>

Africa. The institutionalization of competitive funding was a remarkable achievement for Uganda, as it is typically a lengthy process in developing countries (Crawford et al. 2006; Guimón 2013). This competitive research funding mechanism has positioned Uganda at the forefront of stimulating scientific excellence in East Africa. The success of the MSI Project in introducing competitive STI funding in Uganda provided a solid foundation for future interventions in this sector, ensuring Uganda's continued engagement in a highly competitive knowledge economy.

#### *Government support to scientists (GSS) initiative*

The GSS initiative aimed to eliminate obstacles in the research, innovation, product development, and commercialization process that are typically difficult for scientists and innovators to overcome (Brar et al. 2010, 2011; UNCST 2016b). Administered by the UNCST, GSS was established to motivate scientific innovation among local scientists. The initiative supported projects from the fiscal years 2004/2005–2013/2014, that developed products and a diverse array of applicable technologies (Table 3).

The computer software for disease diagnosis and drug inventory control applications was piloted at Mulago Hospital and National Medical Stores and has since been adapted for use in other sectors. Innovators have already

acquired or are in the process of obtaining intellectual property rights for their research products and processes. Many projects have successfully commercialized their products in both local and international markets (Brar et al. 2010; NPA 2020). As a result of the GSS initiative, research findings have been transformed into practical industrial products and services, leading to the emergence of local scientific enterprises. The GSS initiative was then streamlined into the NSTIP to competitively support near-market scientific research and innovation in priority areas of national development.

#### *National science, technology, and innovation programme (NSTIP)*

The priorities of the NSTIP are outlined in the NDP and national strategic guidelines, which aim to facilitate Uganda's attainment of middle-income status by 2040 (NPA 2007, 2020). These guidelines seek to modernize Uganda through the creation of jobs and inclusive development. The guidelines also serve as a framework for aligning Uganda's international commitments, such as the African Union's recommendation to allocate 1% of GDP to R&D funding under the Science, Technology, and Innovation Strategy for Africa (STISA) 2024 and the Sustainable Development Goals (SDGs), specifically goal number 1 to eradicate extreme poverty and goal number 9 to build resilient infrastructure, promote

**Table 3:** Key GSS, NSTIP and innovation fund outputs.

UNCST Programme	Outputs
Government Support to Scientists (GSS)	<ul style="list-style-type: none"> <li>(a) Artavol®, a malaria-prevention beverage</li> <li>(b) <i>Snailtox</i>®, a pesticide used to control snails that are vectors for bilharzia in humans and liver fluke disease in livestock</li> <li>(c) <i>Kezabu</i>®, an industrially produced banana juice product</li> <li>(d) <i>FREVASEMA</i>®, vacuum-sealed fresh matooke with a longer shelf life for both local and international markets</li> <li>(e) <i>MakaPads</i>®, a product made from local materials and designed to be accessible to schoolgirls, refugees, and other low-income groups</li> <li>(f) Affordable housing technology and water storage tanks</li> <li>(g) Gravity irrigation technology</li> <li>(h) Granary technology</li> <li>(i) Computer software for disease diagnosis and drug inventory control</li> </ul>
National Science, Technology, and Innovation Programme (NSTIP)	<ul style="list-style-type: none"> <li>(a) Paper strip (litmus test) diagnostic tool for TB detection at the point of care at Mulago Hospital</li> <li>(b) Anti-tick vaccine for the prevention of ticks and tick-borne diseases in cattle</li> <li>(c) Affordable, patient-centred computer software that improves patient care by incorporating key patient safety features for efficient health service delivery</li> <li>(d) Low-cost device or platform to measure HIV viral load</li> <li>(e) Low-cost Internet of Things-based soil condition monitoring technology for sustainable agricultural production</li> <li>(f) Agro-process waste management system</li> <li>(g) A locally fabricated gasifier</li> <li>(h) Pox vaccine for the control of epidemics in goats and sheep</li> </ul>
Innovation Fund	<ul style="list-style-type: none"> <li>(a) Low-cost solar powered water pumps for small holder farmers</li> <li>(b) Tear gas from locally sourced plant materials</li> <li>(c) Sericulture technologies, silk-based textiles as tools for household wealth creation and employment generation</li> <li>(d) Production of Bugarama super banana wine</li> <li>(e) Modified products from cassava flour for industrial and food use</li> <li>(f) Local banana juice (<i>Eshandy</i>®) production to answer industrial raw material demand</li> <li>(g) Tropical fruit wines for improved rural household incomes and reduced post-harvest losses of fruits</li> </ul>

inclusive and sustainable industrialization, and foster innovation.

As indicated in [Table 3](#), the key outputs of the NSTIP are at various stages of commercialization and industrial applications. Drawing from the experiences gained in the design and implementation of MSI and GSS, the UNCST facilitated the piloting, standardization, and commercialization of successful innovations through the NSTIP. The NSTIP funded several research and innovation (R&I) projects led by researchers affiliated with various universities and research institutions across Uganda. The UNCST, in collaboration with other STI sector agencies, created guidelines for administering the NSTIP using transparent, accountable, inclusive, and sustainable methodologies to maximize efficiency and impact.

#### *Innovation fund*

The Innovation Fund was established to promote an increase in the number of researchers and innovators who can generate and apply new knowledge to developmental challenges such as food and nutrition, sustainable agriculture, climate change mitigation, adaptation and resilience, access to clean energy, value addition, and access to affordable healthcare. The Innovation Fund was initially implemented in the Financial Year 2017/18

by the UNCST and other stakeholders in the STI sector. The fund assisted in making transformational STI investments that have the potential to generate significant and sustainable economic, social, and environmental benefits in Uganda (UNCST 2016a). It also strengthened Uganda's STI capabilities and performance in the medium term; supported the uptake of research results leading to enhanced national productivity and growth; strengthened Uganda's human resources and research productivity for social and economic transformation; and supported the growth of small and medium enterprises (SMEs) by supporting research, development, and innovation initiatives using multidisciplinary and multi-sector research teams.

The Fund financed several projects in the sectors of agriculture, energy, security, environment, education, and health. These projects were at different stages of development, with some in the R&D phase and others in the initial stages of commercialization (UNCST 2016a, 2016b). The Fund achieved significant results ([Table 3](#)), created 107 direct jobs through project implementation activities, and trained 4837 Ugandans in various sub-counties in banana and pineapple winemaking, poultry farming, piggery, livestock management, cassava processing, sericulture technologies, and good agronomical practices. Eight SMEs were registered and

certified by the Uganda Registration Services Bureau (URSB) in different regions across the country, providing employment for over 1270 Ugandans and generating taxable revenue for the GoU. These accomplishments have contributed to the development of an STI-led society in Uganda.

#### *Science granting councils initiative (SGCI) in sub-Saharan Africa*

The SGCI in sub-Saharan Africa was funded by a consortium of donors from the National Research Foundation (South Africa), International Development Research Centre (Canada), Department of International Development (United Kingdom), and Swedish International Development Agency (SIDA). According to Sadeski et al. (2023), the SGCI aims to strengthen Africa's innovation ecosystems by improving the capacity of Science Granting Councils (SGCs) to implement policies based on robust STI indicators, among other objectives. The initiative conducted regional training and capacity-building initiatives to collect and analyze STI statistics in collaboration with the New Partnership for African Development (NEPAD). It also builds the capacity of policy analysts and statisticians to design and monitor research programmes and develop and implement policies based on robust STI indicators (Hanlin, Tigabu, and Sheikheldin 2020; Sadeski et al. 2023). The initiative trained three staff members at the UNCST in policy relevant STI statistics and indicators organized by the NEPAD. Additionally, the project coordinated the competitive selection and award of five regional EAC and two bilateral R&I grants with Cote d'Ivoire in food and beverage manufacturing/value addition.

According to experts in the STI sector, SGCI has been recognized as enhancing the capabilities of SGCs in their primary focus areas. However, there is some skepticism regarding the utilization of collaborative technical agencies (CTAs), as some of these agencies may have relatively limited capacity compared to SGCs or may not be fully integrated into the participating countries' STI ecosystems, as highlighted by Sadeski et al. (2023). The SGCI has highlighted the need to expand national initiatives to regional and international levels to achieve greater synergies and impact on societal challenges of both national and international significance. It has been suggested that the UNCST embraces international initiatives that can help address its national challenges.

#### *Eastern Africa regional research network for biotechnology, biosafety, and biotechnology policy development (BIO-EARN)*

According to Forsman and Virgin (2011) and From (2016), the BIO-EARN Programme cultivated the necessary capacity and competencies to effectively utilize and integrate modern biotechnology in agriculture, industry, and environmental management in Eastern Africa. The first and second phases of the BIO-EARN Programme (1999–2005) focused on building human and infrastructural capacity in advanced agricultural, environmental, and industrial biotechnology, as well as on developing bio-policy and biosafety

regulatory skills. These phases were coordinated by the Stockholm Environment Institute (SEI) in collaboration with the UNCST. The programme was positively evaluated in 2004, leading to the implementation of the third phase (2006–2009) in the region, coordinated by the Inter-University Council for East Africa (IUCEA). In this phase, the capacity of African scientists and policy-makers built in the first and second phases of BIO-EARN was leveraged to develop nine large regional research consortia involving science and market actors engaged in research for development (R4D) with a focus on crop productivity, agro-processing, and environmental and industrial development.

The BIO-EARN Programme, which operated from 1999 to 2009, engaged 35 institutions in Ethiopia, Kenya, Tanzania, Uganda, and Sweden and involved over 100 scientists, policymakers, and practitioners from the region. As a 'regional network of excellence,' the programme successfully enhanced the capacity of Eastern African countries in biosciences, biotechnology policy, and biosafety assessment, as supported by Forsman and Virgin (2011) and From (2016). In addition, the programme has led to the development of new products, such as improved varieties of sorghum, cassava, and sweet potatoes, and new bioprocess technologies for wastewater treatment and energy production. The programme also served as a platform for collaboration and information-sharing on biotechnology and biosafety policy issues within the region.

#### *Coordination and advancement of sub-Saharan Africa-EU science & technology cooperation network (CAAST-NET)*

Based on CAAST-Net Plus (2015) and Lançon, Ndisi, and Sers (2016), CAAST-NET has assisted in fostering the advancement of scientific and technological cooperation to address global challenges in sub-Saharan Africa and the European Union. To this end, the project played a vital role in the development of roadmaps for implementing the STISA 2024 priority programmes on health for all, sustainable food and nutrition, and climate resilience. Throughout its fifth work package, the project significantly enhanced the capacity of 52 national contact points (NCPs) and 300 national information points (NIPs) in Africa to manage European Union-supported Horizon 2020 programmes. The project activities were conducted under the auspices of the European Union, funded by the CAAST-Net Plus Project, as highlighted by Lançon, Ndisi, and Sers (2016).

Additionally, the project collaborated with the Research Institute for Sustainable Development (IRD) in France and the CTAs to develop knowledge management and communication strategies (KMCS) for food, nutrition, and sustainable agriculture. Furthermore, the project created a database of actors and research findings in the areas of food, nutrition, and sustainable agriculture, which has been instrumental in identifying African and European experts to design and implement food, nutrition, and sustainable agriculture roadmaps. The project also built the capacity of 45 climate change researchers in the EAC region in collaboration with the United

Nations Environment Program (UNEP) and Research Council of Norway (RCN) to study climate change adaptation, mitigation, and resilience (Lançon, Ndisi, and Sers 2016; CAAST-Net Plus 2015).

According to experts in the STI sector, high-level policy dialogues aim to bring together regional and continental experts. However, the African Union Commission's Directorate of STI could have played a more significant role in building and brokering research partnerships between Europe and Africa at the national level, as well as ensuring increased participation in the framework programmes and Horizon 2020 by providing seed funding, as supported by Plus (2015). The key lesson learned is the need to harness mutual research priorities between Africa and Europe, as defined in the Joint Africa–EU Strategy, to leverage resources and capabilities across the two continents and address shared challenges. It is recommended that the UNCST participates more in activities that promote international research, such as Horizon 2020, to facilitate greater knowledge sharing and technology transfer to accelerate national development.

#### *Bio-resource innovations network for Eastern Africa development (Bio-Innovate)*

The Bio-Innovate programme promoted bioscience and product-oriented innovation activities in Eastern Africa, encompassing Burundi, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda. According to Ecuru et al. (2011) and Liavoga and Leta (2016), the programme sought to enhance the delivery of new products through bioscience innovation systems involving a diverse range of stakeholders, including scientists, private-sector entities, NGOs, and other practitioners. The programme concentrated on employing modern bioscience techniques to improve crop productivity and resilience to climate change in small-scale farming systems as well as boosting the efficiency of the agro-processing industry to add value to local bio-resources in a sustainable manner. Bio-Innovate was designed with a user-, market-, and development-oriented approach to achieve tangible results on the ground, support poverty alleviation, and foster sustainable economic growth.

The Bio-Innovate programme brought together partners in Eastern Africa for bio-resource innovation. It consists of four interconnected thematic areas, each of which is aligned with the AU/NEPAD Consolidated Plan of Action for Africa's Science and Technology. These thematic areas include (i) enhancing climate change adaptability, productivity, value addition, and improvement of food and nutrition security; (ii) treating agro-processing waste, utilizing bio-energy from renewable bio-resources, and securing freshwater resources; (iii) fostering innovation incubation and promoting targeted value chains; and (iv) analyzing bio-resource innovation policy and ensuring sustainability (Ecuru et al. 2011; Liavoga and Leta 2016).

The programme established a competitive grant scheme (CGS) to fund more than 10 regional multidisciplinary innovation projects/consortia within the four thematic areas. The call for proposals was framed based on

the four Bio-Innovate thematic areas, priority needs, and regional strategies, with an initial focus on climate change adaptation, according to Ecuru et al. (2011). The selection criteria place strong emphasis on the active involvement of market actors and practitioners, ensuring that knowledge and technologies are used in response to real needs and that efforts and investments are sustainable. Matching funds and long-term commitment from market actors and governments in the region, and potential co-financing with other donor agencies were also considered to approve funding for various project consortia.

#### *Development research uptake in sub-Saharan Africa (DRUSSA)*

According to Barugahara and Harber (2017) and Duncan and Oliver (2017), the DRUSSA programme aims to improve the use of evidence in public policymaking, as there is currently limited usage of evidence in developing countries such as Uganda. The project promoted the generation and utilization of research results from African universities. The project produced policy notes on agricultural commodity value chains for maize, beans, and bee products in Uganda as well as on predictors of the quality of universal primary education in Uganda. In addition, the project resulted in key considerations for a review of the National Energy Policy (Twinomuhangi, Kato, and Sebbit 2022). These policy notes and working papers were used as background materials for 12 thematic policy symposia involving over 500 policymakers and subject matter specialists. These symposia contributed to the review of the Energy Policy (Twinomuhangi, Kato, and Sebbit 2022), the development of a Comprehensive Early Childhood Education Policy in 2017, and the development of the Agriculture Sector Investment Plan (2016/17–2020/2021).

The project further placed six policy fellows to build the capacity of the staff in the ministries responsible for education, energy, and agriculture in evidence-based policymaking. The fellows produced 8 research articles, 9 research reports, and six policy briefs. As an outcome, the project increased the demand for and use of research evidence in policy-making in the participating ministries and built a capacity of over 100 senior – and principal-level policymakers in the MDAs in evidence-based policymaking in collaboration with the Economic Policy Research Centre (EPRC) and Civil Service College-Uganda (CSCU), as evidenced by Barugahara and Harber (2017) and Duncan and Oliver (2017). DRUSSA impacted the policy-making process in Uganda by building the capacity of policymakers to use evidence-based policymaking and influencing the amendment of policy-making guidelines to demand or require empirical evidence for policymaking.

According to experts in the STI sector, a significant portion of the DRUSSA project was allocated to enhance communication of research in universities. A smaller component was dedicated to policy, which was implemented for only three years, thereby limiting the scope of its impact, as supported in Barugahara and Harber (2017). The embedding of fellows takes longer

**Table 4:** Global innovation index scores, 2017–2023.

Country	2017	2018	2019	2020	2021	2022	2023
Top score	67.69	68.40	67.24	66.08	65.50	64.60	67.60
Uganda	26.97	25.32	25.60	20.54	20.00	15.70	16.00
Kenya	30.95	31.07	31.13	26.13	27.50	22.70	21.20
Rwanda	27.36	26.54	27.38	25.06	23.90	18.70	20.60
Lowest score	15.64	15.04	14.49	13.56	15.00	11.60	10.30

Source: GII 2017–2023.

for in-house capacity-building to achieve efficiency gains in evidence-based policymaking in MDAs. The key lesson learned was the need to demonstrate the relevance and contribution of research to policy and national development. It is recommended to establish sustainable mechanisms for linking research to policy and decision making in both the public and private sectors.

### *STI system performance indicators*

According to Brar et al. (2010), evaluating the growth of STI in nascent systems such as Uganda presents a significant challenge. However, the UNCST has utilized various indicators to provide a comparable assessment of Uganda's progress in the realm of STI. These indicators include both globally recommended international best practices, and those tailored to meet specific national requirements. Typically, STI indicators are calibrated over medium-to long-term periods, with mild changes expected to occur in the short-term, as supported by Aktar et al. (2021). These system-level indicators are contributed by various actors within the STI ecosystem, and the UNCST has contributed to the four thematic areas of policy, research regulation, grant management, and capacity-building. The following indicators provide a snapshot of Uganda's STI indicators.

### *Global innovation index (GII)*

The GII, a widely respected measure of the development of a country's STI system, indicates that Uganda's GII scores have been on a downward trajectory since 2017 despite a brief period of improvement in 2019 (Dutta et al. 2022). This is reflected in Table 4, which shows the rankings of Uganda and other East African Community (EAC) countries. Uganda's most recent GII score is significantly below the average score of 33.86 for the thirty-four upper middle-income countries included in the 2018 World Intellectual Property Organization (WIPO) Global Innovation Index Report. This level of technological innovation performance, with an absolute overall GII score in the range of 33–36, is equivalent to

the scores of countries such as Brazil, Colombia, Costa Rica, Iran, Serbia, and South Africa, as summarized in Dutta et al. (2022). However, as shown in Table 4, Uganda's GII scores did not improve and fell further behind those of benchmark countries.

According to Dutta et al. (2022), Uganda's GII score exhibits a few areas of strength, such as the regulatory environment and general infrastructure, which mainly comprise electricity access and communication infrastructure, including roads, but not STI-specific infrastructure and innovation linkages. The positive aspects of the latter include the percentage of R&D funding from abroad and the linkages between the industry and researchers/innovators. However, the scores revealed weaknesses in online creativity, knowledge diffusion, knowledge absorption, knowledge workers, and levels of technology investment.

### *Technology achievement index (TAI)*

According to UNCST (2016a) and NPA (2020), Uganda is classified as a net importer of technology with a Technology Achievement Index (TAI) of 0.24, placing it in the same category as other developing technologically marginalized nations. The limited technological efforts of domestic industries, coupled with the inability to convert public R&D efforts into productive improvements due to difficulties in utilizing and diffusing information and skills, contribute to this situation, as supported by Incekara, Sengun, and Tugba (2017) and Amballoor and Naik (2021). This challenge is compounded by the absence of a strong domestic STI human capital base. In 2010, at the start of NDP I, Uganda's overall TAI score was 0.15, which placed it in the lowest category of countries that made marginal use of technology. This poor ranking was largely due to low scores for new technology creation, the diffusion of existing technologies (as measured by low levels of Internet hosting and low levels of medium – and high-technology exports), and human skills. However, Uganda's 2010 TAI ranking for the diffusion of old innovations was relatively high, reflecting

**Table 5:** Gross expenditure on R&D 2014.

Field of science	Spending (UGX million)				
	Business	Government	Higher education	Private non-profit	Total
Natural sciences	335.5	1,779.2	6,081.6	120.8	8,317.1
Agriculture and veterinary sciences	678.2	14,456.0	14,226.6	108.8	29,469.6
Engineering, technology, and computing	3,121.3	15,512.4	11,131.5	633.9	30,399.1
Medical and health sciences	200.2	1,167.6	12,977.7	674.3	15,019.8
Social sciences	775.5	22,518.0	7,982.1	997.8	32,273.4
Total	5,110.7	55,433.2	52,399.5	2,535.6	115,497.0

Source: UNCST (2016b).

good performance in electricity consumption per capita and the number of telephone subscribers. The targets set for TAI in the NDP and Uganda Vision 2040 aim to reach 0.5 by 2040 (NPA 2007, 2020).

*Gross expenditure on research and development (GERD)* Information on Uganda's Gross Expenditure on R&D (GERD) was obtained from an R&D survey conducted by UNCST in 2014 (UNCST 2016b). Table 5 presents an overview of R&D expenditure by field and funding source for 2014. Overall, GERD decreased from Uganda shillings (Ushs) 167 billion in 2010 to Ushs 115 billion in 2014, representing a decrease of 39%. The primary cause of this decline is the significant reduction in private sector business spending on R&D, which fell from 40% of the overall GERD in 2010 to only 4% in 2014, according to (UNCST 2016b). By contrast, the combined government and higher education spending on R&D increased between the two years.

According to recent data, there has been an unfavourable trend in the opposite direction of national targets for GERD as a percentage of the GDP. Although NDP II set the goal of achieving a gross R&D spending level of 1.0% of GDP by 2020, the actual figures for 2014 indicate a significant decline in GERD as a percentage of GDP relative to the 2010 baseline (UNCST 2016a, 2016b). Consequently, like the GII/TAI indicator mentioned earlier, the overall progress towards an essential NDP II objective for the STI sector was severely off-track.

The second key finding indicates that attaining the 1.0% target for GERD as a percentage of GDP is extremely challenging without a substantial increase in private-sector investment in R&D. It is impractical to assume that the considerable decrease in private sector R&D spending observed in 2014 could be entirely reversed through increased efforts from the public sector and development partner financing (Sithole 2020; UNCST 2016b). Although a higher level of public funding may be essential for reaching the target, this will not be sufficient. To achieve the 1.0% target for GERD as a percentage of GDP, it is necessary to develop a strategy that engages the private sector and encourages new private investment in the STI sector, in addition to increased public funding.

### ***R&D grants and investment impact analysis in key sectors***

#### *Private sector*

The convergence of complementary synergies between the private sector, researchers, and scientists equipped with scientific knowledge and skills has been facilitated by UNCST's establishment of technology platforms. These platforms were designed to promote technology acquisition by private-sector players, as discussed below.

Pamoja Clean Tech is a for-profit social enterprise established in 2010 with a focus on providing rural decentralized renewable energy solutions. The organization utilizes the power pallet gassing corncocks as a foundation for developing a range of energy services. Pamoja received support from the MSI Project to conduct this work, which was also supported by Crawford et al.

(2006). The company set up a microgrid in Tiribogo Village in Mpigi District, which services over 70 of the 105 households in the area, as well as a cell phone tower and several small businesses. Furthermore, in collaboration with the GoU, Pamoja commissioned a new power plant in Sekanyonyi in 2015 that included a mini-grid, providing light for an entire off-grid community. This has led to the growth of local women micro-entrepreneurs, who offer services such as battery recharging and electric lantern rentals. In addition, Pamoja owns agro-processing units, including maize milling machines, which offer agro-processing services to farmers in off-grid areas, thereby increasing their income through value addition and job creation, as highlighted in Crawford et al. (2006) and Guimón (2013).

*Makapads* are low-cost sanitary products supported by UNCST and developed at the College of Engineering, Design, Art, and Technology, Makerere University. They are made from papyrus and paper, resulting in a cost reduction of approximately 50%. Makapad's innovation addresses the issue of school absenteeism due to menstruation, as many girls are unable to attend classes during this period, as supported by Brar et al. (2010) and (Guimón 2013). In addition, *Makapads* are of great use among refugees in Uganda and former Lord's Resistance Army abductees in eastern and northern Uganda.

*FREVASEMA®* is a brand name for value-added bananas, specifically the Fresh Vacuum Sealed Matooke, which can remain fresh for up to six months in a frozen state. Technology and product development were supported by UNCST, and the invention was trademarked and patented, as noted by Brar et al. (2010) and Guimón (2013). The inventor has successfully commercialized the product through Afri-banana (U) Ltd, which exports approximately two tons of *FREVASEMA®* bananas per week to the United Kingdom, Dubai, and North America, primarily to the Ugandans living there. Additionally, vacuum-sealed bananas are available in the major supermarkets in Uganda. Afri-banana (U) Ltd also processes matooke by-products into various products, such as biodegradable bags, textile materials, briquettes, wine, enriched animal feeds, and vinegar.

#### *Industrial sector*

The UNCST provided support for institutional strengthening of the Uganda Industrial Research Institute (UIRI). Through the MSI project, investments were made in the UIRI, which led to the establishment or upgrading of resource centres, including technology development, microbiology, chemistry laboratories, and engineering workshops, as highlighted by Crawford et al. (2006) and Guimón (2013). These centres enabled the UIRI to provide support and incubation services, prototyping, and market testing to SMEs. Additionally, over 1500 individuals received hands-on training through these centres, which also supports the development of low-technology cottage industries in rural areas and incubates more businesses.

The UIRI serves as the foremost agency for the advancement of industrialization in Uganda. Its origins can be traced back to the East African Federation of the

1970s when it operated as a precursor to the East African Research Organization (EARSO). Following the dissolution of the EARSO in 1997, it was reorganized into the Kenya Industrial Research and Development Institute. The creation of the UIRI resulted from negotiations between the GoU and the Chinese Government, which provided a grant to construct and equip the institute. With funding from the UNCST and MSI projects, the UIRI is equipped to play a crucial role in promoting industrial development and practical training for technicians and science teachers (Collins and Rhoads 2010; Crawford et al. 2006). The Technology Development Center (TDC) has undertaken numerous value-added projects, including bamboo, ceramics, food processing, carpentry products, and natural soap production. Currently, the UIRI assists in approximately 30 incubates, ten of which are located in-house. These incubates primarily utilize pilot processing plants, where they receive training on expensive equipment that would not be accessible through traditional bank loans because of the need to convince banks of the technical and commercial capabilities of entrepreneurs and their employees.

#### *Agricultural sector*

In the agricultural sector, the UNCST has made significant strides in addressing the challenges posed by the cassava mosaic virus, which has severely impacted many households, as well as in developing nutritionally enhanced crops such as vitamin A-rich sweet potatoes. To address these challenges, UNCST has provided funding for various agricultural projects through its MSI, GSS, and NSTIP funding facilities. As a result, several innovative research products have emerged, including but not limited to cattle feeds for milk enhancement, value-added cereal products, banana rapid multiplication products and protocols, novel diagnostic tools for domestic animals and poultry, models for monitoring climate change, crop improvement technologies, vaccines and research products that control tropical parasitic diseases of livestock, various products from bananas and other crops, food value addition technologies, and others as noted by Brar et al. (2010) and Guimón (2013). Many of these products and intellectual assets have already been scaled up and commercialized.

Research initiatives have yielded practical solutions, linkages, and entrepreneurship development, resulting in the creation of wealth and the enhancement of nutritional value. Numerous agri-business specialists, managers, crop scientists, plant breeders, and veterinarians have been trained to drive innovative research into agricultural improvement and sustainability. According to Brar et al. (2010) and Guimón (2013), UNCST has supported research aimed at contributing to food security, income generation, and livelihood improvement by scaling up disease-free tissue culture and banana planting material production in Uganda. Consequently, the efficiency of banana production increased, positively affecting income generation and security. Agro-Genetic Technologies (AGT) Ltd, the first private commercial biotechnology (tissue culture) laboratory in Uganda, utilizes tissue culture techniques to produce vast quantities of clean

planting materials. AGT is currently the largest tissue culture laboratory in East and Central Africa, with the capacity to produce over one million clean planting materials per year, depending on crop type. AGT Laboratories received initial financial support from the UNCST in 2003.

#### *Energy sector*

According to Twaha et al. (2016), Uganda's energy sector is a significant recipient of both government and private sector investment. As of 2012, Uganda's total primary energy consumption was 0.0593 quadrillion Btu, which translates to approximately 14.94 million tons of oil equivalent. Biomass remains the primary source of energy for most Ugandan populations. To expand its power supply, the government is constructing micro-hydro projects along the Nile River and promoting the development of other renewable energy sources, such as off-grid solar power systems. In addition, the government is exploring options for developing geothermal reserves in Western Uganda. UNCST has also contributed to this national agenda by promoting the adoption of efficient and sustainable energy sources, as highlighted by Mwampamba, Owen, and Pigaht (2013).

The UNCST, through the Islamic Development Bank (IsDB), received a grant to conduct a pilot programme focused on the transfer and commercialization of charcoal manufacturing technology to farmers and entrepreneurs in Uganda (Mwampamba, Owen, and Pigaht 2013). This initiative aimed to enhance livelihoods, create employment opportunities, and increase income through technology transfers. The project also provided education to local communities on the production and utilization of the new technology (charcoal briquettes), development of micro-enterprises, and marketing of the briquettes and emphasized the environmental concerns associated with using wood charcoal. The project aimed to mitigate deforestation and encourage afforestation strategies in 20 districts across Uganda where over 600 participants were trained.

Multiple organizations and private companies have increasingly invested in the development of clean cooking options by providing various technologies including fuels, biogas, and improved stoves. Green Bio Energy Ltd. The number of charcoal briquette producers and consumers has increased gradually since the introduction of this technology. As a result of this project, there has been an increase in tree cover and in awareness of the consequences of environmental degradation, as supported by Mwampamba, Owen, and Pigaht (2013) and Twaha et al. (2016). The UNCST secured new national and international partnerships related to charcoal briquettes, and charcoal briquette production led to the creation of new employment and income sources. For example, in 2017, the African Development Bank awarded a grant of US\$1 million to Earth Energy Limited for the development of a 20 MW biomass power plant in northern Uganda. The Ministry of Energy and Mineral Development has established a department dedicated to biomass to ensure sustainable biomass supply and efficient utilization of biomass resources.

*Education sector*

The higher education sector in Uganda has experienced significant growth in enrolment and institutions over the past decade. However, despite this expansion, the sector was not adequately aligned with the development needs of the region (Collins and Rhoads 2010). It is mainly input-driven and historically underfunded, with insufficient attention paid to performance and outcomes. At the inception of the UNCST, the tertiary education system faced a shortage of human resources at the institutional level with only 550 faculty members holding PhDs. This resulted in a high student-to-faculty ratio of 200:1 and limited the number of students pursuing S&T. Enrolment in S&T disciplines consistently remained low at 15% of the total higher education enrolment, which was well below the worldwide average of 38% and SSA's average of 25%, according to Muriisa and Rwabiyoma (2019). Additionally, there have been virtually no published papers in the basic sciences, particularly in fields such as chemistry, physics, mathematics, engineering, and earth sciences. Consequently, the knowledge and human capital required for economic growth are severely limited, particularly that required by the local market. The UNCST has contributed significantly to an increase in the number of STE graduates at all levels of tertiary education, as supported by Crawford et al. (2006) and Collins and Rhoads (2010). For example, the MSI project helped train approximately 3600 BSc, 57 MSc, and 31 PhD students in various STE fields.

According to Crawford et al. (2006) and Collins and Rhoads (2010), the UNCST provides financial assistance to universities to establish new S&T programmes or improve existing ones. Ten grants were awarded, four for new programmes and six for upgraded programmes. The UNCST supported the establishment of new bachelor's degree programmes in textile engineering, biosystems engineering, and biotechnology at Gulu, Makerere, and Busitema Universities. Additionally, two programmes were established at Kabale and Kyambogo universities to train secondary school teachers in mathematics and science. The UNCST also supported the updating of programmes in physics, medicine, surveying, and pharmaceutical sciences at Makerere and Mbarara Universities. Furthermore, the UNCST has supported the development of new science curricula, accredited by the National Council for Higher Education. The UNCST also provided support for establishing the STI infrastructure. This included the establishment of laboratories, training faculty members, provision of equipment, and development of infrastructure.

*Health sector*

According to Ongâ and Abbey (2019), low life expectancy in Uganda can be attributed to a multitude of local health challenges. Infectious diseases, which account for 40-50% of all illnesses in the country, including malaria and tuberculosis, continue to pose a significant threat despite being virtually eliminated in other parts of the world. These diseases also hinder the export of African livestock and transmission of diseases from animals to humans. Inadequate capacity for health research, poor

utilization of resources in traditional medicine, and knowledge production for drugs and vaccines have exacerbated this situation. Additionally, the rise of non-communicable diseases such as cancer has had a recent impact. The high prevalence of genital human papillomavirus infection, absence of radiotherapy, and lack of a national cervical cancer prevention and control programme have contributed to the expected increase in deaths from this disease (Ongâ and Abbey 2019).

UNCST has been at the forefront of the battle against cancer by supporting targeted interventions aimed at improving its management. In particular, the UNCST plays a key role in the establishment of long-term surveillance for carcinogenic genital human papillomavirus (HPV) infections and sexual behaviours among girls, as supported by Kapiriri, Ekochu, and Nabudere (2020). This initiative provides vital information to policymakers regarding HPV vaccination in Uganda. Therefore, HPV vaccination is now included as part of the vaccine received by teenage girls in Uganda. Additionally, the UNCST has supported the implementation of new curricula for medical training, with a focus on community-based education (Kapiriri, Ekochu, and Nabudere 2020).

*ARTAVOL*® is a malaria-prevention herbal drink supported by the UNCST and produced at the Natural Chemotherapeutic Research Laboratory and Makerere University. This prophylactic medicine has proven to be effective in preventing malaria and has been available in pharmacies in Uganda since 2013, following successful laboratory studies, animal studies, and community trials spanning three years as reported by Brar et al. (2010). Regular consumption of this beverage for one year can render a person immune to malaria. The product was packaged as granules and sold in tins of 100 grams. In addition to its primary function as a malaria prevention measure, it can also be consumed as a beverage or functional food to prevent frequent fever and worm infestations and possesses antioxidant properties.

*Information and communication technology (ICT) sector*

The UNCST collaborated with the Ministry of Information and Works, Housing, and Transport to formulate the National Information and Communication Technology (ICT) Policy in 2003. This policy aimed to address the policy and regulatory gaps arising from the convergence of information and communication technologies, thereby facilitating the growth of the ICT sector in Uganda. As a result, the Ministry of ICT was established, and a thriving ICT sector emerged. To some extent, Uganda's success in the ICT sector can be attributed to the pioneering initiatives of the UNCST (Onapa, Sebbale, and Aguirre-Bastos n.d.).

According to Brar et al. (2010) and Guimón (2013), the UNCST implemented and supported two projects aimed at developing affordable, patient-centered integrated computer software to improve patient care by incorporating key patient safety features and facilitating efficient health service delivery. The software, which is used mainly for rapid disease diagnosis and drug stock control in pharmaceutical and medical supply management, patient-centered health management informatics

systems, health staff management, and hospital administration, was piloted at Mulago Hospital, Kisiizi Hospital, and Rugarama Hospital. Consequently, a widely applicable system was developed that is appropriate for use in resource-poor health facilities across the country (Brar et al. 2010; Ongâ and Abbey 2019). Medical staff in these health facilities are trained in computer software applications and comprehensive, accurate, and real-time database management to provide a quality evidence base for the assessment of disease trends and outcomes.

In addition, UNCST has supported the development of other ICT platforms, including the Automated Cargo and Vehicle Management (ACRAV) system, which is an investment in computer-based management to improve productivity and profitability in the transport sector (Bowman 2019; Brar et al. 2010). The information system provides a collaborative portal that brings transit companies and agents together, thereby increasing visibility and freight control. The project developed a fleet management system that enabled cheap tracking of vehicles and maintained a computerized update of the company's assets and liabilities. It is now possible to use ubiquitous telecommunications infrastructure with 80% national coverage as a means of communication between the ACRAV information system, transit companies, and agents using SMS messages and data via the Internet.

According to Bowman (2019) and Breitenbach and Malan (2020), the International Development Research Cooperation (IDRC) through the Acacia Project supported the utilization of ICT by piloting the multi-purpose rural telecenter model to promote the adoption of ICT through shared access. The project established three telecenters in rural and peri-urban areas in Uganda, located in Nabweru, Buwama, and Nakaseke. These telecenters serve as access points and demonstration centres for rural communities on a range of ICTs, including pay telephones, fax machines, photocopiers, and several computers equipped with basic software and connected to a telephone line, thus enabling access to emails and the Internet. The Buwama Telecenter transitioned to a community radio station, Radio Buwama 103.3 FM, with an estimated daily listenership of over 50,000 people. Telecenters promoted shared access, which evolved into individual access through the 3G and 4G networks. They also stimulated rural economic activity by promoting various uses including social communication and business transactions, particularly in agriculture and local retail trade, as highlighted by Bowman (2019). The telecenters were replicated throughout the country through other projects and private service providers as viable commercial enterprises, and their ownership and operations were transferred to the communities as part of the sustainability mechanism. Currently, 65% of the population has access to ICT networks, compared with the limited access that existed when the first telecenters were established under this model.

The observed connections between ICT and poverty reduction have been utilized by the ACACIA project in Uganda to improve rural livelihoods and employment as well as to enhance the efficiency of service delivery

methods. The telecenter model, which was successful across the African continent, demonstrated that communities are willing to adopt technologies that address their immediate needs and challenges, regardless of complexity (Bowman 2019; Breitenbach and Malan 2020). Therefore, it is recommended that the UNCST identify, promote, and implement more transformative technologies through pro-poor interventions, as it is the utility of the technology rather than its complexity, which determines its adoption and use.

### **Key intervention areas and lessons learned**

The UNCST has demonstrated its capacity to administer a competitive funding facility with utmost transparency, and the government has not interfered with the process. The technical committee awarded grants based on clear selection criteria consistent with international best practices, resulting in high-quality proposals, keen competition, and accountability for the grants. The current R&D grants and investment situation indicate a growing trend in regional engagement and a heightened interest in programmes aimed at transferring ownership to Uganda. In addition to increased national funding, new players, such as SGCI, have emerged in regional research funding and support. UNCST can continue to tap into international funds, but it is crucial to carefully consider which international funders prioritize co-funding arrangements and assess their potential impact on national ownership. The UNCST must minimize overlap in funding initiatives and avoid conflicting goals between regional and national efforts.

### **Funding for research and development (R&D)**

The UNCST has played a pivotal role in Uganda's rapidly evolving STI funding landscape. The government increased its commitment to research funding, resulting in an increase in the rate of scientific production and innovation. Additionally, new organizations have emerged to fund STI, and there has been a notable increase in cross-regional research collaboration. Uganda pledged to increase its GERD by 1% following the Lagos Plan of Action (NPA 2020). Although progress has been slow, there is a clear upward trend in budgetary allocation to R&D.

Investment in the STI sector necessitates the adoption of novel approaches to sector investment financing, including increased private participation through public-private partnerships (PPPs) and foreign direct investment (FDI). A national research fund could serve as a viable mechanism for augmenting research and establishing programmes for STI graduates. However, its efficacy may be amplified by extending the capacity building and technical assistance to grantees. The caliber of the research proposals received by the UNCST indicates that Uganda boasts many exceptional researchers who lack the technology, networks, funding, and skills required to secure sustainable research funding. Therefore, UNCST should provide more intentional and targeted support to researchers and innovators.

*STI policy advice and implementation*

UNCST has demonstrated that promoting a knowledge-based economy requires a comprehensive approach that engages multiple MDAs and the private sector. The complex challenges within and across STI ecosystems require focused and coordinated effort. The UNCST has laid the foundation for a national data system on STI for the medium-to long-term. Although the UNCST achieved several objectives, its coordinating mandate was significantly hindered by the absence of a systematic approach to address the prevailing STI challenges. Despite these efforts, the national STI ecosystem remains weak, and further institutional strengthening is needed to combine all elements of the system. In addition, STI data and statistical systems require further improvement. Although the Uganda Bureau of Statistics (UBOS) assisted the UNCST in establishing research management information systems under the Plan for National Statistical Development (PNSD), additional capacity building was necessary for the collection, storage, dissemination, and analysis of STI information.

*Improved research programming and performance*

The UNCST has played a pivotal role in fostering interdisciplinary collaboration and problem-solving, enabling the integration of diverse fields and disciplines. Over the past 15 years, the UNCST has been instrumental in tracking the progress of research in Uganda and guiding national research priorities in key sectors, such as agriculture, medicine, engineering, and the humanities. By supporting initiatives in emerging trans – or interdisciplinary areas, as well as consolidating existing efforts into more strategic and long-term programmes, the UNCST has demonstrated its commitment to advancing research in Uganda.

*STI institutional strengthening*

UNCST has played a significant role in building the capacities and capabilities of research institutions and universities. Through the establishment of over 25 research ethics committees across various agencies, the UNCST has established a globally recognized and exemplary research ethics system that serves as a best-practice example in Africa. Since its inception, UNCST has supported the formation of research teams across different research institutes and universities. Under MSI, the UNCST disbursed over Ush. 15 billion to 12 research teams for health research, including malaria vaccine studies and clinical trials, as well as for increased and sustainable fish production, food security, and climate change mitigation. Such research teams have led to various breakthroughs and innovations in medicine, engineering, and arts. These research teams have also brought together senior and junior researchers, as well as individuals from diverse backgrounds, such as women and men, and business and academic members who produce higher-quality work.

*STI partnerships and collaboration*

The findings of this study shed light on the significant role played by the UNCST in Uganda's transition to a middle-

income and prosperous country. The UNCST made a noteworthy contribution to Uganda's efforts in food, nutrition, and sustainable agriculture. Through the development and support of targeted programmes and cutting-edge scientific research, the UNCST has helped farmers increase their crop yields by providing stronger seeds and greener fertilizers. Additionally, UNCST has played a key role in the development of new agricultural markets, expansion of trade, and adoption of technologies in several value chains, such as the use of mobile phones to provide real-time prices. Moreover, the UNCST has supported sustainable agricultural practices and capacity-building efforts within communities, enabling them to become self-sufficient without depleting their natural resources. The UNCST is at the forefront of these science-driven initiatives and provides financial and technical support. As a result, UNCST established strong partnerships with the private sector to encourage private investment in Ugandan agriculture.

UNCST has played a leading role in advancing climate change research and promoting innovation to mitigate the effects of desertification and foster climate-friendly economic growth. The UNCST has placed a strong emphasis on protecting biodiversity, maintaining functional ecosystems, and promoting climate change adaptation, mitigation, and resilience. During the MSI period, the UNCST successfully developed comprehensive competencies in competitive grant management, as well as other related capacities, such as procurement, monitoring and evaluation, and grant proposal writing. The successful implementation of MSI also demonstrates the feasibility of establishing and implementing a world-class science research fund in low-income countries. Grants were awarded through a clear and transparent selection process that adhered to international best practices, leading to high-quality proposals and strong competition and accountability for the awarded funds. Despite progress in this area, women continue to be underrepresented in the economy and STI, and further efforts are needed to promote their inclusion in sustainable human capital development outcomes in this field. The UNCST has taken steps to amplify the role of women in science through various publications, public events, and media campaigns; however, much work remains to be done.

*Challenges and recommended actions*

Despite these efforts, the UNCST faces several challenges, including limited capacity, inadequate funding, overlapping roles with other agencies, absence of appropriate legislation, and difficulties in implementing science and research funding policies. These issues have hindered progress in certain sectors and diminished the sustainability of programme outcomes. Additionally, the lack of STI priorities over an extended period negatively affected the overall effectiveness of these efforts.

The UNCST must maintain momentum in gathering STI indicators to support the evidence-based formulation of effective STI policies. The UNCST should collaborate closely with partners to regularly report the standard STI indicators needed to inform the national STI discourse. Additionally, the UNCST should work closely with

regional experts, such as the National Research Foundation of South Africa, to collect STI indicators. To ensure consistency with global reporting frameworks, the collection of STI evidence for policies must be disaggregated by gender. This requires persistent efforts to change attitudes about women pursuing careers in STI, as well as addressing constraints such as unfriendly educational environments and the lack of role models.

The presence of disparate agendas for R&D granting and investment at both the national and regional levels pose a challenge. To address this issue, the UNCST could promote discussions of the implications of various regional funders on Uganda's national STI priorities. It is not possible to assume that there is an alignment of agendas or a common understanding of the funding criteria. The establishment of sub-regional bodies may be beneficial in formulating more specific agendas that align with goals within the EAC region. To sustainably fund STI, the government must play a more proactive role. In other words, it is essential to establish an appropriate cost-sharing agreement between the government and donors to ensure funding sustainability. The government was provided with an MSI grant for nearly all operational costs, and some of the benefits achieved during MSI should have been sustained through government support alone. It is crucial to track funding for the UNCST and the cost and effectiveness implications of the different institutional configurations. Additionally, monitoring UNCST governance arrangements and spending on the administration would enable analysis and comparison.

UNCST should work closely with other agencies within the STI system to develop a robust national R&D system. Currently, the system is scattered with many entities implementing entity-specific mandates, resulting in duplication and latent inefficiencies. Developing a comprehensive R&D database and outlining categories of research being conducted, by whom, and where, can help streamline research performance in the country. Additionally, the UNCST should strengthen its collaboration with STI partners to improve the collection and dissemination of STI data within the region and facilitate better reporting and benchmarking.

At both the national and regional levels, the private sector plays a crucial role in R&D granting and investment in the STI sector. However, private sector funding is currently low, and engagement is inconsistent throughout Uganda's STI sector. To increase private sector involvement, dedicated efforts are necessary, and there is a need to explore communication strategies and mechanisms between the public and private sectors regarding the value of different types of research. The UNCST may need to allocate additional resources to private-sector research activities and explore the roles of other civil society actors. This study revealed the need for UNCST to actively engage with and influence researchers and universities, both public and private, through individual research agreements or collective agreements with a group of universities. Additionally, the UNCST should establish direct working arrangements with individual researchers to achieve a targeted impact on the national research agenda.

## Conclusion

### *Theoretical implications*

R&D funding and technological innovation are positively correlated, whereas financial structure and support are significantly related to scientific and technological innovation (Hogan et al. 2022; Kurekova et al. 2023). Government R&D investment has been shown to enhance scientific and technological performance, although its effect on commercialization is not evident (Pisár, Ďurčeková, and Stachová 2020). A combination of different funding sources, including R&D grants, can positively affect innovation outcomes (Acebo and Miguel-Dávila 2024). However, the efficiency of financial organizations and environmental regulations can have varying impacts on the commercialization of R&D innovation (Chen et al. 2023). The literature indicates that government grants do not crowd out private funding but stimulate private R&D expenditure, with private funding positively influencing innovation (Acebo and Miguel-Dávila 2024; Kurekova et al. 2023). Additionally, the relationship between R&D grants and innovation is nuanced and influenced by factors such as firm lobbying, industry competition, and geographic dispersion (Unsal and Houston 2023).

R&D funding is positively correlated with R&D outcomes in sustainable development; however, disparities exist among the states (Kurekova et al. 2023). Subsidiary R&D support through grants and tax credits can lead to significant firm performance payoffs in the host economy (Lenihan et al. 2023). The innovation spirit of micro and small enterprises (MSEs) significantly promotes innovation performance, with R&D investment serving as an internal transmission mechanism (Yin et al. 2023). Public support for R&D has a positive effect on private investment in business R&D in the EU (Pisár, Ďurčeková, and Stachová 2020). Therefore, the theoretical implications drawn from the literature suggest that R&D grants and investments can contribute positively to innovation commercialization. This is contingent on the presence of a supportive financial structure, combination of various funding sources, and influence of environmental and firm-specific factors.

### *Policy implications*

The GoU, through the UNCST, must maintain momentum in gathering STI indicators to support the evidence-based formulation of effective STI policies. Furthermore, the UNCST should collaborate closely with its partners to regularly report the standard STI indicators required to inform national STI discourse. The effectiveness of R&D grants in stimulating innovation is evident, as they have a significant impact on product and process innovation (Acebo and Miguel-Dávila 2024). In addition, government R&D funding has been shown to enhance scientific and technological performance (Lenihan et al. 2023). However, the commercialization of government-funded R&D is not guaranteed, as indicated by the lack of an effect on commercialization in the context of government R&D funding (Yin et al. 2023). This suggests that, while R&D grants are crucial for innovation, additional mechanisms may be needed to translate these

innovations into marketable products and services. Fiscal incentives, including tax policies, have been highlighted as complementary measures for facilitating investment in R&D and innovation (Zhang et al. 2023).

Moreover, it emphasizes the importance of considering the characteristics of the technology sector and regional characteristics when allocating government R&D funding (Yin et al. 2023; Zhang et al. 2023). This is particularly relevant in Uganda where regional disparities and sector-specific challenges may exist. Policies should not only provide R&D grants, but also ensure that these grants are part of a broader policy mix that includes fiscal incentives and considers the specificities of different sectors and regions. Additionally, mechanisms to support the commercialization of innovations should be integrated into the R&D funding framework to maximize the economic impact of such investments. The findings from the literature underscore the need for a nuanced approach to R&D funding beyond the provision of grants to include supportive measures for commercialization (Acebo and Miguel-Dávila 2024; Yin et al. 2023; Zhang et al. 2023).

#### **Ideas for future research**

Future research on the contribution of R&D grants and investment to the commercialization of innovations in Uganda could benefit from a multi-faceted approach. It would be valuable to investigate the effectiveness of R&D grants in fostering product and process innovation in Ugandan firms (Acebo and Miguel-Dávila 2024).

The literature provides interesting facts when considering the influence of regional industrial structures on innovation outcomes. For instance, specialized versus diversified regional industry structures have been shown to moderate the impact of enterprise R&D investments on product innovation performance (Zhang et al. 2023). This finding suggests that the regional context of Uganda may play a critical role in the success of R&D investment. Furthermore, the presence of local technology leaders can attract and deter inward R&D investments (Yin et al. 2023), indicating that the dynamics of local industrial clusters could be a significant factor in Uganda.

Future research should explore the direct impact of R&D grants on innovation in Uganda, the role of regional industrial structures, and the influence of local technology leaders. It would also be beneficial to consider the types of ownership and firm age in relation to R&D investments (Zhu, Zhao, and Abbas 2020) as well as the potential for R&D grants to support energy efficiency and green technology advancements (Yin and Chang 2021). Finally, the impact of foreign-owned subsidiaries on national R&D and the effectiveness of policy instruments, such as R&D grants and tax credits, in the Ugandan context should be examined (Lenihan et al. 2023). These areas of research could provide a comprehensive understanding of how R&D grants and investments contribute to the commercialization of innovations in Uganda (Acebo and Miguel-Dávila 2024; Lenihan et al. 2023; Yin et al. 2023; Zhang et al. 2023).

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#### **Authors' contributions**

All authors contributed to the writing of the manuscript and have read and approved the final manuscript.

#### **Data availability statement**

The datasets/documents used and analyzed during the current study are available from the corresponding author upon reasonable request.

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## **PAPER IV**

RESEARCH

Open Access



# The drivers and barriers influencing the commercialization of innovations at research and innovation institutions in Uganda: a systemic, infrastructural, and financial approach

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## Abstract

Research and innovation (R&I) institutions must commercialize their innovations to remain competitive in a knowledge-based economy. While R&I institutions in Uganda have the potential to drive socioeconomic development, a clear understanding of the commercialization pathway is lacking. This study aims to bridge this gap by analyzing the systemic, infrastructural, and financial factors that drive and hinder the commercialization of innovations at R&I institutions in Uganda. This study offers the first comprehensive examination of the systemic, infrastructural, and financial dimensions influencing innovation commercialization within Uganda's R&I ecosystem, presenting new empirical evidence on the prioritized barriers and drivers as perceived by key stakeholders. Employing a mixed-method approach, this study uniquely combines quantitative surveys with qualitative case studies and key informant interviews, enabling a nuanced understanding of the multifaceted drivers of and barriers to innovation commercialization in Uganda. The study employed the Delphi technique to identify consensus among key informants. The findings highlight the urgent barriers to address, including fragmented R&I ecosystems, inadequate support infrastructure, such as technology transfer offices, and significant gaps in innovation financing. These issues underscore the urgent need for targeted policy interventions. Based on our findings, we recommend the establishment of a national innovation fund, enhancement of public private partnerships for R&D infrastructure development, and formulation of a cohesive national policy framework to streamline commercialization processes at R&I institutions. This study provides policymakers with a data-driven foundation to craft targeted interventions aimed at removing the identified barriers, thereby catalyzing the commercialization of innovations in Uganda's R&I institutions.

**Keywords:** Barriers, Commercialization, Drivers, Innovations, Research and innovation institutions, Uganda

## Introduction

Innovation is a valuable resource for research and innovation (R&I) institutions, and many developing countries have prioritized its commercialization and utilization (Aktar et al., 2021; Ecuru et al., 2014; Kreiterling, 2023; Kurpayanidi, 2021). Uganda's investment in innovation, technology development, and transfer, expressed as gross expenditure on research and development (GERD), is currently 0.18%, which is below the 1% recommended by the African Union (NPA, 2020; Sithole, 2020). The products of innovation generation, diffusion, and exploitation are crucial to a country's economic growth, competitiveness, and transformation. Many developed countries attribute their success to the knowledge economy, which is characterized by well-established innovation and commercialization systems (Atwine et al., 2023; OECD, 2021; Schwab & Zahidi, 2020).

Innovation and commercialization are two key processes that are vital for converting knowledge and ideas into commercially viable products and services. Research and development (R&D) plays a crucial role in the innovation process, and the availability of adequate support infrastructure, financing mechanisms, and a well-coordinated R&I ecosystem are essential for successful commercialization. These elements facilitate the transfer of knowledge from knowledge generators such as research institutions and universities to knowledge consumers such as techno-business firms and industrial actors. The conversion of innovative products into profits is the primary goal of commercialization, which relies on the creation of market value for novel goods, processes, and services (Bakhtiar et al., 2020; Kruachottikul et al., 2023).

The Government of Uganda (GOU) acknowledges the crucial role of R&I in establishing a competitive and knowledge-based economy that addresses socioeconomic transformation issues (Mulumba et al., 2017; NPA, 2020; Sithole, 2020). Consequently, the GOU has shown political will by positioning science, technology, and innovation (STI) at the forefront of the country's transformation and growth processes. This is exemplified by the creation of the innovation, technology development, and transfer (ITDT) program under the Third National Development Plan (NDP), as well as the development of a supportive regulatory and institutional environment (NPA, 2020) in the country.

The commercialization of innovations has been demonstrated to yield substantial returns, with estimated returns of 30% in the commercial sector and 50% in the social sector (Schwab & Zahidi, 2020). Despite these benefits, Uganda does not invest significantly in innovation and commercialization (Mulumba et al., 2017; NPA, 2020; Sithole, 2020). Research and innovation contribute up to 3% of the Gross Domestic Product (GDP) of developed and emerging industrialized countries (OECD, 2016; Schwab & Zahidi, 2020). As such, Uganda's socioeconomic development plan must prioritize the advancement of scientific and technological innovation (Mulumba et al., 2017; NPA, 2020; World Bank, 2021).

Notwithstanding these observations, there are compelling reasons for researchers and innovators to gain a comprehensive understanding of the process of commercializing their ideas. This is particularly important if the country aims to achieve its transformation agenda. The successful commercialization of innovations is essential to unlock their full potential benefits, as recognized by several scholars

(Bakhtiar et al., 2020; Kruachottikul et al., 2023). Product commercialization is a clear indication of the true value of an invention and serves as a strategic driver of economic growth and development for firms (Bakhtiar et al., 2020; Kruachottikul et al., 2023).

According to Ecuru et al. (2014), the commercialization process in Uganda faces systemic barriers, yet detailed insights into these barriers remain scarce. Our study aims to delve deeper into these systemic issues, providing a nuanced understanding that previous research has overlooked. Inadequate comprehension of the structure and functionality of the country's innovation and commercialization processes hinders investment in R&I (Asad et al., 2023; World Bank, 2021). This lack of understanding adversely affects the learning process and interaction among the various stakeholders in the R&I ecosystem (Abbas et al., 2018; Martins et al., 2023). As a result, policymakers and stakeholders in the R&I ecosystem are constrained in their ability to devise and implement strategies to promote the development of the country's innovation and commercialization systems (Abate & Sheferaw, 2023; Aktar et al., 2021). Consequently, research, innovation, and commercialization programs are at risk of being underutilized, and their value, relevance, and impact are frequently underestimated.

While previous studies have highlighted the role of commercialization in driving economic growth in developing countries (Butnik-Siverskyi et al., 2024; Min et al., 2020; Shcherbachenko & Kotenko, 2022), there remains a limited understanding of the specific systemic, infrastructural, and financial challenges faced by R&I institutions in Uganda. This study seeks to address this knowledge gap by conducting a comprehensive examination of the systemic, infrastructural, and financial dimensions influencing innovation commercialization within Uganda's R&I ecosystem, presenting new empirical evidence on the prioritized barriers and drivers as perceived by key stakeholders. This study is guided by three pivotal research questions: What are the systemic drivers and barriers impacting innovation commercialization in Uganda? How do infrastructure issues influence this process? What financial challenges do R&I institutions face and how can these be addressed?

Unlike previous studies, which have mainly focused on systemic, infrastructural, or financial aspects in isolation (Gong et al., 2021; Loganathan & Subrahmanya, 2022; Shcherbachenko & Kotenko, 2022), our study adopts a comprehensive approach that integrates all three dimensions. This holistic view is crucial for developing targeted interventions that can effectively enhance the commercialization capabilities of R&I institutions in Uganda. The findings underscore the critical importance of a fully integrated R&I ecosystem that requires both institutional and national support mechanisms. This study provides a viable solution that can be utilized to formulate effective policies and foster the creation of a commercialization strategy for the country. This, in turn, leads to increased efficiency and productivity in Uganda's R&I institutions. The study recommends that the government and its partners encourage collaboration and knowledge sharing among the various stakeholders in the R&I ecosystem, enhance R&D infrastructure, and broaden the scope of innovation and commercialization financing channels at Ugandan R&I institutions.

The following sections of this paper will discuss the literature review, research methodology, study findings and discussion, contextual analysis of the systemic,

infrastructural, and financial drivers and barriers, recommended measures and strategies to overcome the systemic, infrastructural, and financial barriers, and the conclusion.

## **Review of literature**

### **The Triple Helix model's role in innovation commercialization**

The Triple Helix model characterizes the connection between creators of knowledge, users of knowledge, and the government as well as their involvement in a knowledge-based economy (Abbas et al., 2019; Cai & Etzkowitz, 2020). This model emphasizes collaboration, cooperation, and co-development among the three institutional spheres of university, industry, and government, with the university playing an enhanced role (Abbas et al., 2019; Cai & Etzkowitz, 2020). In a triple-helix culture, the functions of university, industry, and government change in a manner that enable each institutional sphere to assume the role of others in specific and relevant situations (Abbas et al., 2019; Cai & Etzkowitz, 2020). This means that the Triple Helix concept allows for the overlap of functions and the creation of boundaries or bridging institutions, as collaboration between universities, industry, and the government provides flexibility in institutional boundaries. Entities that generate knowledge include universities, research organizations, science academies, and other science- and technology-related agencies (Abbas et al., 2019; Cai & Etzkowitz, 2020). The government sector comprises science and technology (S&T) policy and legal and regulatory organizations, while knowledge-consuming (industry) entities include manufacturing and services, whether for profit or not.

While Abbas et al. (2019) emphasize the critical role of government support in innovation commercialization, other studies have pointed out instances where excessive government intervention has stifled innovation (Zhang et al., 2023; Zhu et al., 2020). This discrepancy highlights the complex nature of government involvement in innovative ecosystems and underscores the need for a balanced approach. Despite extensive research on the impact of the Triple Helix model on innovation commercialization, there remains a lack of understanding of how this model interacts with local cultural and economic dynamics in Uganda. This approach directly points to gaps and sets the stage for the relevance of the study.

### **Systemic drivers and barriers to innovation commercialization**

The commercialization of innovations is a critical aspect of transformation and growth in both developed and developing countries (Al-Shammari & Waleed, 2018; Fuentelsaz et al., 2019; Kruachottikul et al., 2023). Researchers and innovators have shown considerable interest in this area because of its positive impact on socioeconomic advancement, including the creation of new job opportunities (Atwine et al., 2023; Omri, 2020; Uyarra et al., 2020). Furthermore, the successful execution of projects that contribute to national competitiveness depends on the appropriate commercialization of ideas (Baláž et al., 2023; Khelfaoui & Bernier, 2023; Teixeira et al., 2021).

The current policy climate and framework conditions for research and innovation in a country are constrained by structural and systemic limitations (Fosci et al., 2019; Mulumba et al., 2017; NPA, 2020). The fragmentation of the R&I ecosystem in Uganda, as noted by Mulumba et al. (2017), not only hinders knowledge transfer, but also leads

to the duplication of efforts and inefficient allocation of resources. A closer look at this fragmentation reveals that it stems from the lack of coordinated policy implementation and inadequate platforms for stakeholder engagement. The national R&I ecosystem in Uganda is characterized by a disjointed network of entities with divergent sectoral alignments in budgeting, planning, and service delivery (Mulumba et al., 2017; NPA, 2020; UNCTAD, 2020).

According to Mulumba et al. (2017) and UNCTAD (2020), R&I endeavors are disjointed and lack intersectoral linkages and synergies between public and private sector entities. The absence of platforms for collaborative planning and implementation of synergistic programs hinders intersectoral collaboration, knowledge transfer, and commercialization (Chane & Atwal, 2023; Kruachottikul et al., 2023). Each R&I system player operates in isolation, disregarding related or complementary efforts from other actors that can be harnessed to achieve better results.

Based on the literature reviewed above, our first research question is as follows: Q1: What are the systemic drivers and barriers that impact the commercialization of innovations at the institutional level in Uganda?

This question aims to identify the factors that either facilitate or hinder the systemic aspects of the commercialization process at the institutional level in Uganda. The answers to this question contribute to a better understanding of the systemic challenges faced by institutions in Uganda when attempting to commercialize their innovations.

Following the discussion on systemic barriers, it is crucial to consider infrastructural challenges, as they are intrinsically linked. While systemic issues create a foundational dilemma, infrastructural inadequacies directly impact the operational capability of R&I institutions to innovate and commercialize effectively.

### **Infrastructural promoters and challenges to innovation commercialization**

In recent years, innovation infrastructure has been recognized as a vital component in addressing societal challenges (Kesselring et al., 2023; Uyarra et al., 2020). Public research and innovation (R&I) institutions are increasingly striving to stimulate and support private sector innovation by developing an R&I infrastructure that fosters creative activities (Arora & Chong, 2018; Fudickar & Hottenrott, 2019). As a result, R&I institutions play a crucial role in driving a country's goals towards commercialization, as well as supporting the efficient execution of government infrastructure plans (Mulumba et al., 2017; NPA, 2020; UNCTAD, 2020).

It can be stated that research and innovation institutions aim to bring about beneficial changes and reshape societal realities through rational resource utilization and the establishment of robust infrastructure initiatives (Baláz et al., 2023; Nuruzzaman et al., 2019; Zhu et al., 2020). These institutions not only demonstrate effectiveness but also play a crucial role in the successful commercialization of innovations. Evaluating institutional efficiency in the public sector involves assessing its capacity to implement impactful infrastructure programs and policies while addressing societal needs and concerns and maximizing public value with limited resources (Chen et al., 2018; Khelifaoui & Bernier, 2023; Rivera & Landahl, 2019).

Considering the critical role of infrastructure in supporting innovation (Uyarra et al., 2020), Uganda could benefit from targeted investment in R&D facilities and

technological infrastructure. This approach is supported by UNCST's Engineering Development and Innovation Center (EDIC), where similar investments have led to significant improvements in innovation output (Ogwang & Vanclay, 2021). The current state of research, innovation, and commercialization infrastructure in Ugandan R&I institutions is inadequate. This lack of a national research agenda and priorities limits opportunities for coordinated and consolidated national efforts to develop an R&I infrastructure through demand-driven, shared access, and cost-effective models (Ogwang & Vanclay, 2021; Tweheyo et al., 2024). Access to advanced research facilities is limited, and only a few scientific centers of excellence have such capabilities. Research materials are often transferred to foreign laboratories for analysis at high cost (Ogwang & Vanclay, 2021; Pius & Owin, 2024).

Based on the literature review, our second research question is formulated as follows: Q2: What are the infrastructural drivers and barriers that impact the commercialization of innovations at the institutional level in Uganda?

This question aims to identify the factors that either facilitate or hinder the infrastructural aspects of the commercialization process at the institutional level in Uganda. The answers to this question contribute to a better understanding of the infrastructural challenges faced by institutions in Uganda when attempting to commercialize their innovations.

Following the discussion on systemic and infrastructural barriers, it is crucial to consider the associated financial challenges as they are intrinsically linked. While systemic and infrastructural issues create a foundational dilemma, financial inadequacies directly impact the operational capability of R&I institutions to innovate and commercialize effectively.

### **Financial incentives and constraints to innovation commercialization**

The national R&I ecosystem must meticulously evaluate its financial assets and employ the most effective mechanisms to achieve desired outcomes, including fostering public welfare, enhancing public services, and promoting economic growth, leading to increased employment and higher incomes for citizens (Geissinger et al., 2019; Nuruzzaman et al., 2019). Unfortunately, Uganda's GERD is currently at 0.18%, which is below the level of 1% suggested by the African Union (NPA, 2020; Sithole, 2020), resulting in insufficient financial resources for ordinary (non-grant) support of research institutions, infrastructure, human resources, and other development activities. Furthermore, the grant money is also in short supply, and the government-allocated funding for research is less than the demand stated in the research proposals. Many R&I institutions rely heavily on external funding (Hogan et al., 2022; Kurekova et al., 2023).

Furthermore, the funding available for the translation of research discoveries into commercial products is limited in size and scope, requiring significant investment in infrastructure, equipment, and product development. The financial tools available for R&I activities do not align with the financial and innovation sectors of Uganda. In contrast to Uganda's 0.18% GERD, Kenya invests 0.8% of its GDP in R&D (OECD, 2021), which is closer to the African Union's recommended value of 1% (African Union Commission, 2014). This comparison not only highlights Uganda's relative underinvestment but also suggests that increasing R&D expenditure could be a pivotal

driver for enhancing innovation commercialization. Platforms for connecting academia, researchers, and industry, which can attract venture funding from potential scientific entrepreneurs, are still in their early stages (Fosci et al., 2019; Mulumba et al., 2017; UNCTAD, 2020). Consequently, many researchers are left with immature prototypes and must seek financing throughout the various stages of R&D.

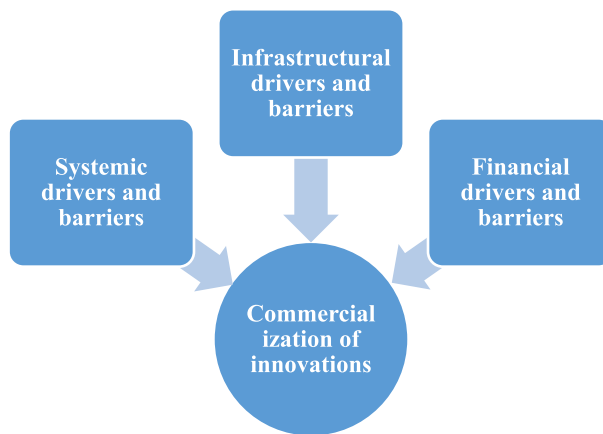
The financing arrangements for R&I are untenable. In the absence of a sufficiently capitalized national research fund, R&D funding is allocated through the national budget framework process, which utilizes the medium-term expenditure framework (MTEF) and annual budget framework paper (BFP) (NPA, 2020). To ensure continuity of funding, the mechanism provides short-term support for R&D activities and requires researchers to provide verifiable research outcomes within a specific fiscal year.

It has been noted that many long-term research initiatives encounter financial sustainability issues due to the significant time lag between research funding and the realization of actual findings, particularly those involving longitudinal studies such as vaccine development and climate change studies (Fosci et al., 2019; NPA, 2020; Zhu et al., 2020). To address this issue, the national R&I fund must either be adequately capitalized, or alternative long-term financing mechanisms for R&D must be developed to provide a resolution to short-term finance and allow for the completion of the R&D cycle.

Our third research question, formulated based on the literature reviewed above, is as follows: Q3: What are the financial drivers and barriers that influence the commercialization of innovations at the institutional level in Uganda?

This question aims to identify the factors that either facilitate or hinder the financial aspects of the commercialization process at the institutional level in Uganda. The answers to this question contribute to a better understanding of the financial challenges faced by institutions in Uganda when attempting to commercialize their innovations.

Based on a literature review and formulation of the research questions, the proposed conceptual model (Fig. 1) was established for this study. The literature review shows that various actors are involved in transforming innovation into marketable products or services. When the conditions are conducive, interactions and learning among these actors occur, resulting in innovations that improve the productivity, commercial



**Fig. 1** A proposed conceptual model (Source: Authors)

viability, and profitability of R&I institutions. To achieve this, actors throughout the R&I ecosystem must grasp the processes of commercializing innovations and surmount barriers to technology adoption and commercialization. However, the existing literature is deficient in empirical theory or explanation regarding the systemic, infrastructural, and financial drivers and associated measures that influence the commercialization of innovations at R&I institutions in Uganda.

## **Method**

### **Study design and approach**

To address the multifaceted nature of commercialization barriers and drivers, this study employed a mixed-methods approach. This methodological choice allows for an in-depth exploration of qualitative insights from key informant interviews and case studies while also enabling the validation of these insights through quantitative data from surveys. This approach is particularly suited to uncovering the nuanced interactions between systemic, infrastructural, and financial factors, which the existing literature has not fully explored. Despite the recognition of systemic, infrastructural, and financial factors as critical to the commercialization of innovations, there remains a gap in empirical studies that comprehensively explore these factors in tandem within the context of Uganda. This study aims to bridge this gap by employing a mixed-method approach to identify and analyze these drivers and barriers in a holistic manner.

The Delphi technique utilized in this study, according to Mohannak and Samtani (2014), involves conducting multiple rounds of surveys with a panel of experts. After each round, the aggregated responses were shared with the panel to refine their views in subsequent rounds. This iterative process is designed to converge on a consensus regarding the most significant systemic, infrastructural, and financial barriers and drivers to innovation commercialization in Uganda, thereby addressing a critical gap in existing empirical research.

Given the identified gap in understanding the private sector's role in innovation commercialization in Uganda, this study specifically aims to dissect how private enterprises and financial institutions contribute to or hinder the commercialization process. By leveraging both qualitative insights from key informant interviews and quantitative survey data, this study seeks to elucidate the mechanisms through which the private sector can either facilitate or obstruct the commercialization of innovations, thus offering targeted recommendations for enhancing private sector engagement.

### **Study population**

Participants were selected from R&I institutions, including universities, research institutes, techno-business firms, incubation/innovation hubs, private/consultancy firms, and non-government organizations (NGOs), based on the following inclusion criteria: (a) involvement in at least one commercialization project within the last five years; (b) holding a position that directly influences R&D decisions, such as project managers, principal researchers, or executives of R&I institutions; and (c) willingness to provide a detailed description of the innovation and commercialization process in their respective institutions. These inclusion criteria for participant selection ensured that the study gathered insights from individuals with first-hand experience in Uganda's

innovation and commercialization landscape. R&I institutions can be broadly classified into four categories: knowledge generators, such as research institutions and universities; knowledge consumers, including techno-business firms and industry actors; government bodies; and support systems, such as incubators and innovation hubs.

### Sampling method

To ensure a representative sample of R&I institutions in Uganda, we calculated the required sample size using a standard formula based on the expected proportion of innovative firms and a confidence level of 95%. Study participants were selected using purposive sampling to ensure a comprehensive understanding of the drivers and barriers that influence innovation commercialization at the institutional level (Holliday, 2014; Manly, 2015).

The sample size was determined using the following formula (Manly, 2015):

$$n = \frac{Z^2 \times [P \times (1 - P)]}{\alpha^2}$$

where;  $\alpha$  is the level of significance;  $e = 5\%$  [error];  $P = 0.917$  [% of innovative firms in Uganda (NPA, 2020; Sithole, 2020); and  $Z = 1.96$  [*Z-value*].

Taking  $\alpha = 5\%$ , Thus

$$n = \frac{1.96^2 \times 0.917 \times 0.083}{0.05^2} = 116$$

Therefore, a sample size of 116 participants was used in this study.

### Data collection

The study was conducted in 2022, and the investigator administered the questionnaires to the participants. Online questionnaires were available to respondents who preferred to complete them on their own. A total of 95 responses were recorded from 116 participants, with a response rate of 82%. The data collection tool aimed to explore the possible drivers and barriers to the commercialization of innovations by focusing on the linkages between the R&I ecosystem and the private sector, R&I support infrastructure, and mechanisms for innovation and commercialization financing at the institutional level.

Key informant interviews were conducted with a diverse range of stakeholders, including scientists/innovators, chief executive officers, business leaders, and administrators in selected organizations, universities, incubators, and firms. The purpose of these interviews and discussions was to gain a comprehensive understanding of the factors that drive and hinder the commercialization of innovations at R&I institutions in Uganda.

The structure of the interview questions was specifically developed to obtain respondents' experiences, opinions, and expectations (OECD/Eurostat, 2018) regarding a firm's systemic, infrastructural, and financial capabilities and networks. The interview session, which lasted for approximately one hour, was conducted at different times and locations. After each interview session, the data collected were transcribed, and the interpretations derived from them were sent to the participants via email for their

approval. Participants' feedback on the interpretation of the data was sought to verify and confirm their accuracy. The participants were allowed to modify any information they believed did not accurately reflect their perspectives and experiences. These subsequent checks by the participants served to prevent researchers' subjective biases from unduly influencing the findings. Emphasis was placed on ensuring the consistency and reliability of the generated data, following the principles outlined by Holliday (2014).

### **Data analysis**

The process of ensuring the accuracy of the collected data involved verifying the completeness and consistency of the questionnaires. In cases where further clarification was necessary, additional information was requested from respondents. The data were then inputted into Microsoft Excel, organized, and thoroughly cleaned before being analyzed using the Statistical Package for Social Scientists (SPSS) 26.0.

The analysis of the generated data was conducted using a three-pronged approach (Lester et al., 2020; Mihas, 2019) and comprised the following three main phases: (i) data reduction, which involved selecting, clustering, abstracting, and transforming the documented transcriptions (interview data) into a usable and manageable form; (ii) data display, which involved organizing the data in a manner that would facilitate the drawing of conclusions. The data were organized into time-ordered matrices and supplemented with information on roles and inputs. (iii) Drawing conclusions and verification: This phase involved evaluating the key results of the study and, in some cases, re-analyzing the data to verify the findings.

An explanation-building procedure was employed in a cross-case analysis (Lester et al., 2020; Mihas, 2019) to gain further insight into the drivers and barriers affecting the commercialization of innovations in R&I institutions in Uganda. Through a comparison of cases, it was possible to determine the general applicability of the findings and to specify the conditions under which those findings hold.

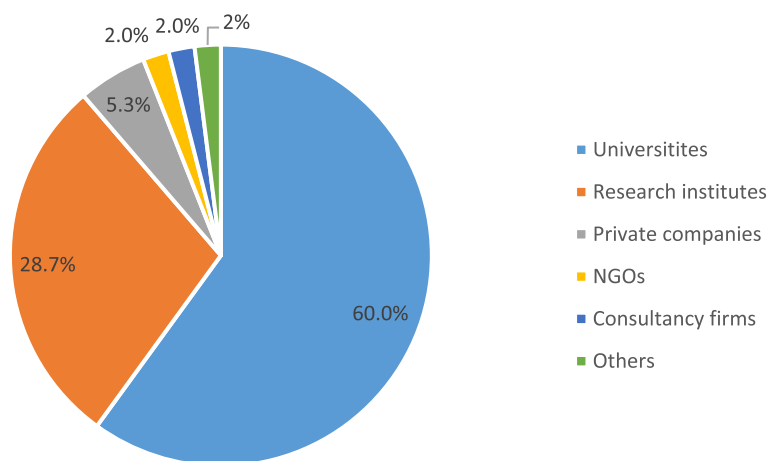
## **Results and discussion**

### **Characteristics of participating research and innovation organizations**

As highlighted by Muriisa and Rwabyoma (2019), R&I institutions in Uganda play a crucial role in the country's growth, competitiveness, and reform programs. These institutions primarily focus on addressing societal needs such as poverty alleviation, food security, and disease prevention. As shown in Fig. 2, various participants in the R&I landscape were identified, including universities (60%), research institutes (28.7%), private companies (5.3%), NGOs (2%), consultancy firms (2%), and others (2%).

### **Understanding the linkages between the research and innovation ecosystem and the private sector**

According to research, the private sector plays a crucial role in the commercialization of innovations, which is vital to the country's economic growth and development (Abbas et al., 2019; Kruachottikul et al., 2023). As a developing country, Uganda relies heavily on innovation and entrepreneurship to drive economic growth and has proposed initiatives to encourage the private sector to participate in these efforts. In recognition of the significance of the private sector, the GOU has implemented measures to create



**Fig. 2** Organizations as a proportion of the total study participants

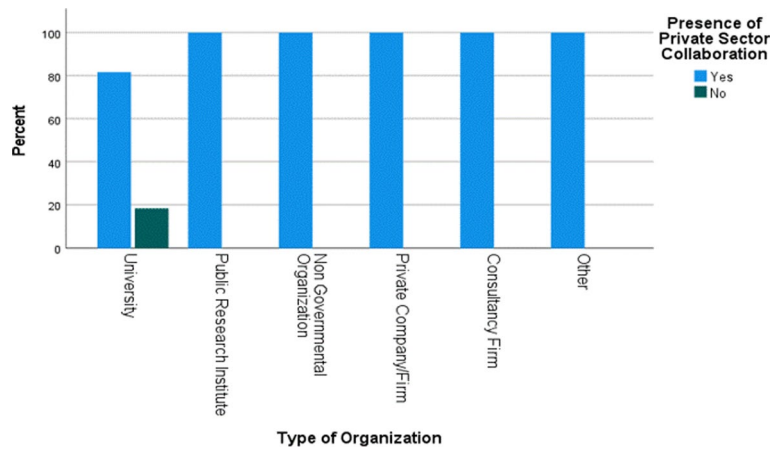
a supportive business environment within the country (Okumu & Buyinza, 2020; Sendawula et al., 2023).

One of the critical knowledge gaps identified is understanding the direct impact of R&I ecosystem fragmentation on the efficiency of resource allocation and information dissemination within Uganda’s innovation landscape (Okumu & Buyinza, 2020). The study findings indicate that fragmentation of the R&I ecosystem is a significant systemic challenge to the commercialization of innovations in Uganda. This study evaluated the connections and collaborations between knowledge-generating organizations such as universities, research institutes, NGOs, private companies, consulting firms, incubation facilities, innovation hubs, and knowledge users, specifically techno-business firms and the private sector (Abbas et al., 2019; Bakhtiar et al., 2020). To enhance the effectiveness of these linkages and cooperation, sectoral fragmentation measures must be implemented across the R&I system.

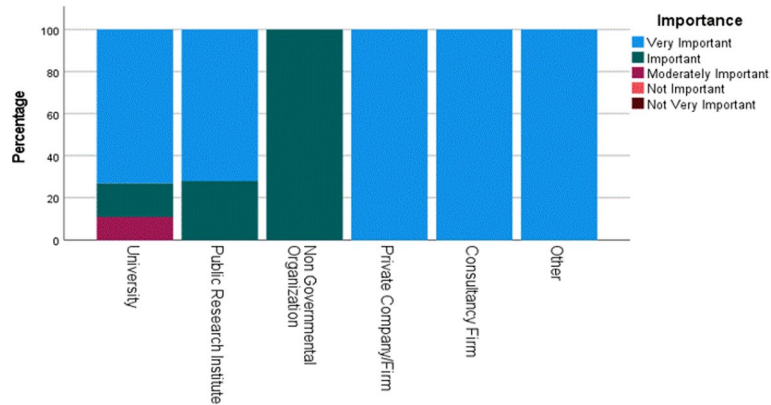
***Private sector collaboration within the different organizational categories***

Several scholars have noted that the connections between R&I institutions and the private sector in Uganda are disjointed and suboptimal despite efforts to strengthen them (Ajer et al., 2023; Okumu & Buyinza, 2020; World Bank, 2021). This is a manifestation of the fragmentation that exists within the R&I ecosystem, which poses a significant obstacle to the commercialization of innovations at the institutional level in Uganda. To foster economic growth and development, the government and other stakeholders are working to create a more favorable environment for collaboration between the R&I ecosystem and the business sector.

Except for limited responses from recently established institutions, all participants reported the presence of private sector participation in the operations of their organizations, as depicted in Fig. 3. Few institutions that did not involve the private sector in their operations are situated upcountry and geographically removed from the country’s major business center, which hosts a higher concentration of private firms and corporations. Some of these institutions were new and still in the early stages of



**Fig. 3** Private sector collaboration within the different organizational categories



**Fig. 4** Importance of collaboration with the private sector

establishing their operations, which hindered their ability to engage in collaborations and interactions with the private sector.

**Importance of collaboration with the private sector**

It was observed that coordination between the business sector, government, and academia is essential for the effective commercialization of innovations in Uganda. By working together, the private sector, government, and academia can establish an environment that fosters entrepreneurship, promotes innovation, and drives sustainable economic growth (Tweheyo et al., 2024; Wang et al., 2024).

Figure 4 illustrates that most R&I institutions, including public universities that were fully funded by the government, considered private-sector collaboration essential to their operations. In contrast, only a small percentage of universities (10%) perceived private-sector collaboration as a moderately important venture.

**Time dedicated to private-sector collaboration**

Several scholars have noted the importance of allocating time for collaboration with the private sector to commercialize innovation (Salmon et al., 2020; Stubbs et al.,

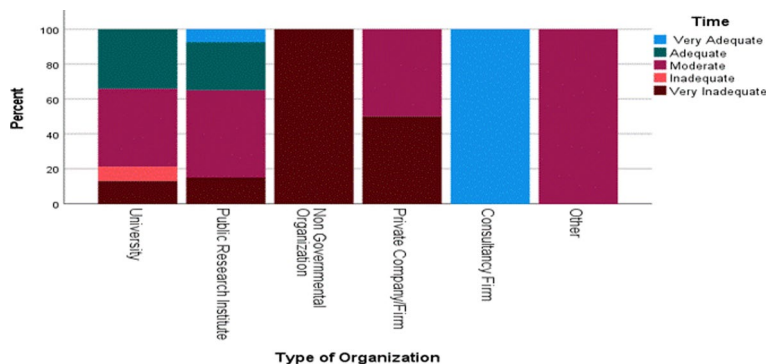
2022). The private sector plays a crucial role in economic growth, job creation, and the introduction of new products and services into the market. By working together, public and private sectors can expedite the innovation process, leading to increased productivity, competitiveness, and societal benefits.

According to the study, private sector collaboration was found to be highly valued in the commercialization of R&D, but most R&I institutions did not allocate sufficient time to promote such collaboration. Consultant firms were an exception, as they dedicated sufficient time to private sector collaboration, as demonstrated in Fig. 5. The study also revealed that consultant firms spent the most time collaborating with the private sector, followed by universities, and research institutes. In contrast, NGOs and private corporations were less dedicated to private-sector collaboration. The limited commitment of NGOs to private sector collaboration can be attributed, in part, to their funders, who often have special interests and restrict NGOs' participation in private sector players to a certain extent.

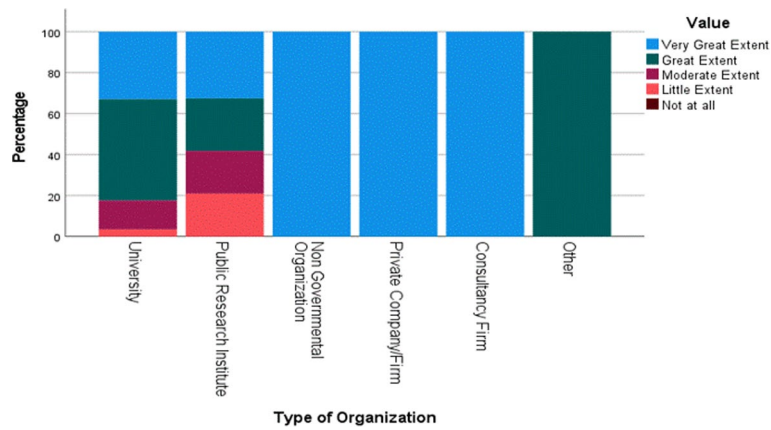
**The value attached to strengthening collaborations with the private sector**

Cooperation between the private sector and R&I institutions in commercializing innovations is of utmost importance for obtaining resources, market validation, industrial expertise, network expansion, risk reduction, and market access, as supported by Abbas et al. (2019) and Martins et al.(2023). Such collaboration leads to economic development, job creation, and the development of innovative solutions to societal problems by connecting creative ideas with commercial success.

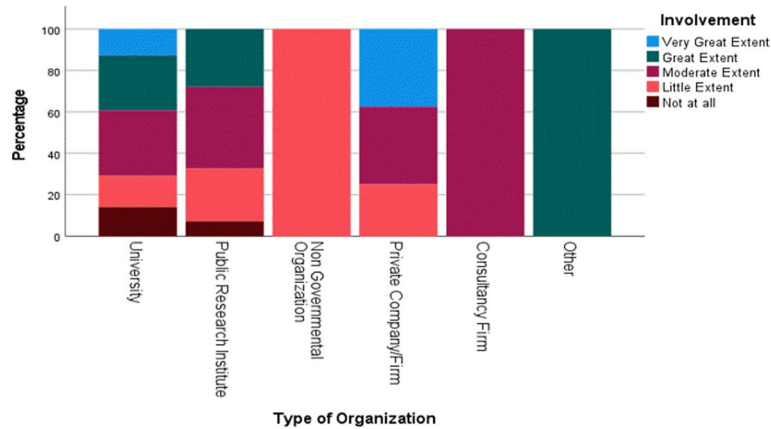
During the study, it was noted that collaboration with the private sector was highly valued by private firms, consulting firms, and NGOs. This was evidenced by the willingness of R&I institutions to encourage staff partnerships with the commercial sector through internships and part-time consultancy as well as by creating opportunities for the corporate sector to participate in events such as public lectures. However, it should be noted that approximately one-fifth of research institutes (20%) placed limited importance on the need to expand private sector partnerships, as shown in Fig. 6.



**Fig. 5** Time dedicated to private sector collaboration



**Fig. 6** Value attached to strengthening collaborations with the private sector



**Fig. 7** Involvement of the private sector in the setting of organizational priorities

***Involvement of the private sector in the setting of organizational priorities***

Based on this research, involvement of the private sector in the formulation of organizational objectives can provide multiple advantages and positively impact an organization’s overall performance. According to Baláz et al. (2023) and Kesselring et al. (2023), this collaboration can provide valuable commercial experience, a market-focused approach, opportunities for risk-sharing, and expedited product development and commercialization. Furthermore, it can help firms align their innovation efforts with market demand, enhance their chances of success, and contribute to economic growth.

The results of the study revealed that a significant proportion of respondents from private businesses (38%) and universities (14%) involved the private sector in the establishment of organizational goals (Fig. 7). Conversely, consulting companies engaged only in the private sector to a moderate extent in this process. Notably, NGOs were not involved in the private sector. The university and research institution respondents generally had positive reactions to the business sector’s engagement in determining organizational priorities, particularly when the private sector was a key stakeholder or partner, and when joint programs or projects were being implemented in the private sector.

### **The contribution of institutional research and innovation support infrastructure**

The study observed that the country's R&D infrastructure is still in its formative stages, with limited access to laboratories and research facilities. To bridge this gap, a detailed study of the optimal allocation and utilization of R&D resources in Uganda's R&I institutions is recommended. This could inform targeted investments in infrastructure that directly contribute to the commercialization process, such as prototyping facilities and technology transfer offices (Pius & Owin, 2024).

However, Uganda has made noticeable strides in upgrading its innovation infrastructure by establishing innovation centers and incubators (Kwesiga, 2019; Ogwang & Vanclay, 2021). The research and innovation support infrastructure provides academics, entrepreneurs, and businesses with the necessary tools, facilities, and support systems to transform their ideas and inventions into marketable products and services. Such infrastructure facilitates the translation of scientific discoveries and technological advancements into practical applications, which significantly contributes to the commercialization of inventions and promotes economic development and societal impact by providing the necessary resources, skills, and support.

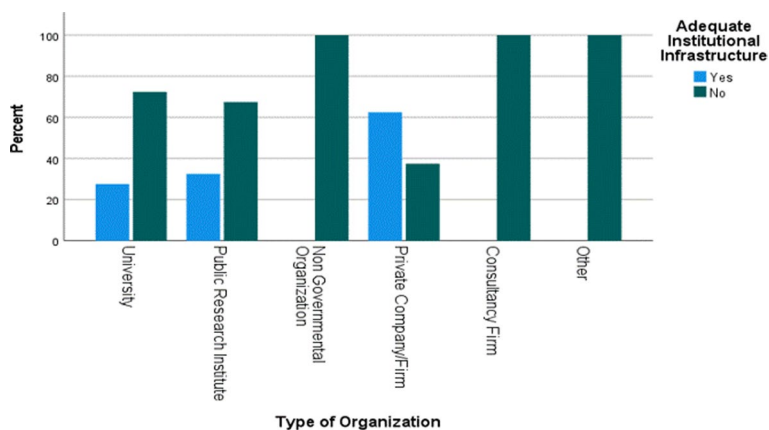
According to Kwesiga (2019) and Pius and Owin (2024), Uganda has demonstrated significant progress in recent years in enhancing its R&I institutions' innovation and commercialization infrastructure. Based on this research, the absence of sufficient R&I infrastructure is a critical issue in Uganda's R&I system. Private enterprises, NGOs, and consultancy firms perceive the existing innovation and commercialization support infrastructure, such as Intellectual Property Management Offices (IPMOs), Technology Transfer Offices (TTOs), and grant management offices (GMOs), to be of less importance due to budgetary constraints, which often hinder their operations.

### ***Availability of institutional R&I infrastructure***

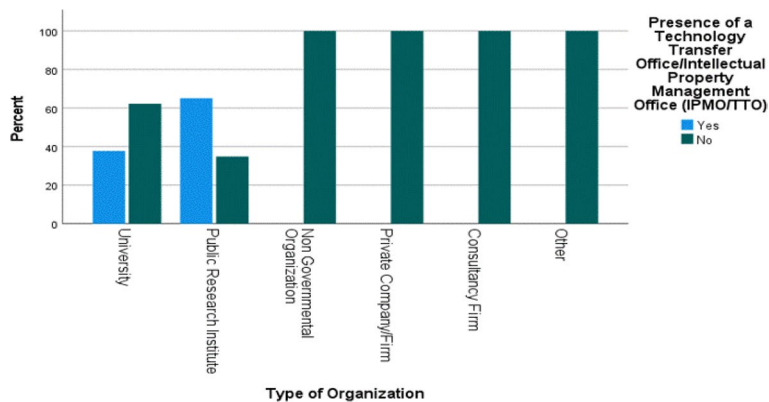
This study analyzed the availability and functionality of institutional infrastructure that supports R&D innovation and commercialization. The study scrutinized IPMOs, TTOs, and GMOs as integral components of the infrastructure that foster innovation and commercialization at the institutional level (Pius & Owin, 2024). Additionally, the study evaluated the availability of institutional intellectual property (IP) policy, financing, and the level of skills or abilities of staff working in IPMOs, TTOs, and GMOs as part of the infrastructure.

The research findings indicate that inadequate R&D support infrastructure is a significant obstacle to commercializing innovations at the institutional level in Uganda. The study discovered that many firms participating in the survey lacked adequate R&D infrastructure (Fig. 8), highlighting the need for increased investment in research, innovation, and technology transfer facilities.

Based on the study results, as depicted in Fig. 8, only private enterprises, research institutions, and universities reported having sufficient institutional infrastructure in the form of laboratories, incubation centers, and workshops. The respondents cited reasons such as the lack of funding and resources for development, as well as the obsolescence of some equipment and technologies in innovation and incubation facilities for those where the support infrastructure was deemed insufficient.



**Fig. 8** Adequacy of institutional infrastructure in the organizations



**Fig. 9** Presence of intellectual property management offices (IPMO) and technology transfer offices (TTO)

***Presence of intellectual property management and technology transfer offices***

Intellectual property management offices (IPMOs) and technology transfer offices (TTOs) play pivotal roles in the commercialization of inventions (Min et al., 2020; Sapah et al., 2022). IPMOs are responsible for safeguarding and managing intellectual property assets, such as patents, trademarks, copyrights, and trade secrets. TTOs facilitate the transfer of technology and knowledge from the academic and research settings to the business sector.

IPMOs and TTOs work together to safeguard and promote new ideas. TTOs facilitate collaboration between academia, research, and the business sector, enabling the exchange of technology and knowledge. IPMOs specialize in the legal aspects of IP protection and licensing, and their cooperation is essential for the successful commercialization of discoveries and their transformation into practical products, services, and economic value (Butnik-Siverskyi et al., 2024; Sapah et al., 2022). As depicted in Fig. 9, TTOs and IPMOs were primarily observed at universities (38%) and public research institutions (63%). This deficiency in the promotion of innovation and commercialization has been identified in private corporations, consulting firms, and NGOs.

**Presence of intellectual property policies**

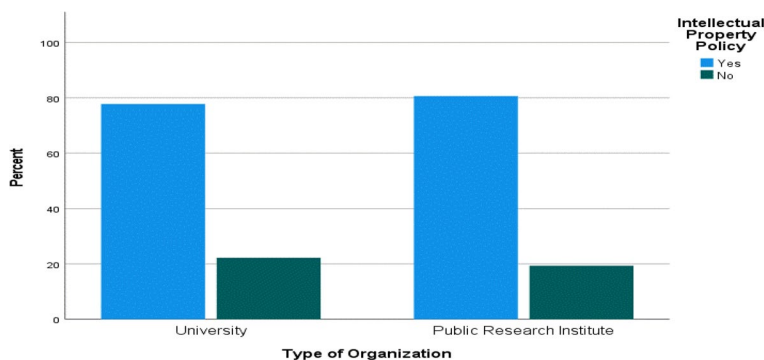
According to Pererva et al. (2024), intellectual property (IP) policies play a crucial role in the commercialization of innovations at R&D institutions. It establishes a legal framework to protect creators’ rights and provides incentives for R&D investment by granting exclusive rights to those who develop or produce something new. The design and execution of institutional IP policies must be geared towards achieving the effective identification, development, protection, and utilization of IP assets. Intellectual property rights (IPRs) promote innovation and creativity by ensuring that R&D findings, discoveries, inventions, and creative work are used to benefit society.

Figure 10 shows that most universities (78%) and public research institutions (80%) with technology transfer offices (TTOs) and intellectual property management offices (IPMOs) have implemented intellectual property (IP) policies. This is because of the critical need for universities and research organizations to have a structured approach to managing the IP assets generated by their R&D outputs (Tahir et al., 2022). To promote innovation and commercialization, all institutions must embrace the development of IP policies. Furthermore, ongoing professional development is vital to enhancing the knowledge and skills of individuals in executing their duties, and the facilitation of mobility between the public and commercial sectors within the R&I ecosystem is crucial.

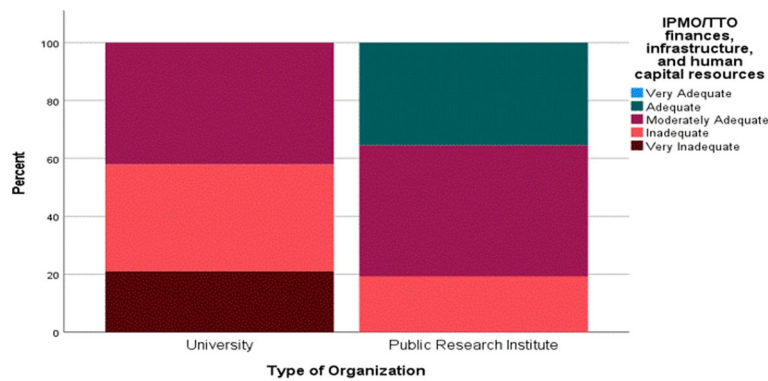
**Availability of resources to intellectual property management and technology transfer offices**

Figures 11 and 12 depict the results of the study on the proficiency levels of IPMOs and TTOs, along with the availability of resources in universities and research institutions. Enterprises are responsible for allocating resources to IPMOs and TTOs to safeguard, manage, and capitalize on their IP assets. This approach fosters innovation, encourages collaboration, enhances the value of IP, and supports R&D (Min et al., 2020).

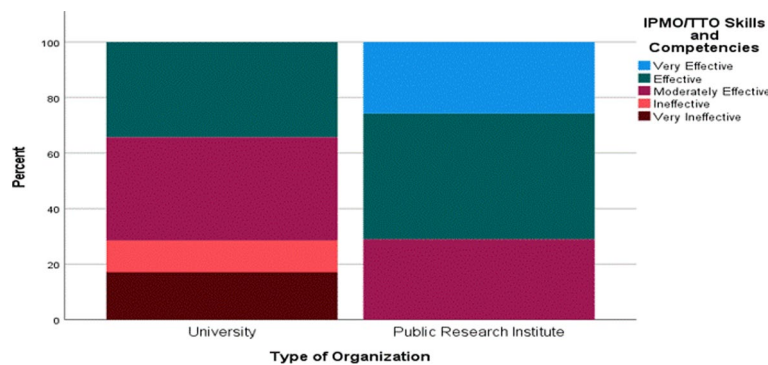
Assessment of IPMOs and TTOs revealed that both universities (40%) and public research institutes (80%) had sufficient resources. However, the capacity of these organizations to facilitate R&D collaboration with the business sector was found to be inadequate. Specifically, up to 20% of university respondents reported that the capacity of IPMOs and TTOs was very limited.



**Fig. 10** Presence of intellectual property policy at universities and research institutes



**Fig. 11** Availability of resources to IPMO/TTO at universities and research institutes



**Fig. 12** IPMO/TTO skills and competencies at universities and research institutes

***Level of skills and competencies in intellectual property management and technology transfer offices***

Adequate skills and abilities are required for IPMOs and TTOs to work effectively. According to Butnik-Siverskyi et al. (2024), these offices play a crucial role in administering and preserving intellectual property assets as well as facilitating the transfer of technology from academic institutions to the business sector. To fulfill their responsibilities successfully, IPMOs and TTOs must possess adequate abilities and competencies. With the necessary competencies, these offices can preserve and utilize intellectual property assets, facilitate technology transfer, and contribute to innovation and economic progress (Min et al., 2020).

In terms of abilities and competencies, IPMOs and TTOs were more prevalent in research institutes (70%) than in universities (34%) (Fig. 12). This phenomenon can be attributed to the fact that certain universities prioritize the advancement of knowledge over the prototyping and commercialization of their research outputs.

**The existing institutional mechanisms for innovation and commercialization financing**

The financial viewpoint examines the financial resources available for innovation and commercialization at R&I institutions in Uganda. Obtaining funding remains a significant challenge for inventors and entrepreneurs in Uganda, particularly during

the early stages of growth. According to Sendawula et al. (2023) and the World Bank (2021), the financial sector in Uganda is underdeveloped with limited access to venture capital and investors. Moreover, many entrepreneurs lack the financial literacy and business acumen required to secure funding and effectively manage their resources. A comparative study with Kenya's mobile technology sector could reveal innovative financing models, such as public private partnership models for funding R&D, that Uganda might emulate to improve its innovation commercialization of finance channels (Atwine et al., 2023).

Idea commercialization often demands significant capital investment and necessitates the establishment of financing mechanisms for innovation and commercialization (Butnik-Siverskyi et al., 2024; Shcherbachenko & Kotenko, 2022). The evaluation of these mechanisms in various organizations was conducted using factors such as the effectiveness of GMOs, the institutional allocation of resources, accessibility to innovation and commercialization resources, and the competencies and skills of GMOs. The study found that the lack of dependable institutional finance systems for research, innovation, and commercialization is a major obstacle hindering the commercialization of innovations in Uganda.

According to this survey, insufficient financing is a significant impediment to the growth of Uganda's research and innovation (R&I) ecosystem. This study analyzed the allocation and availability of financial resources for innovation and commercialization within Ugandan R&I institutions. The successful implementation of innovation and commercialization initiatives is vital for the country's economic development, and financial sustainability is a crucial factor in determining its success (Ajer et al., 2023). To address the existing funding gaps in R&I institutions, this study recommends exploring options, such as pooling resources or establishing joint ventures.

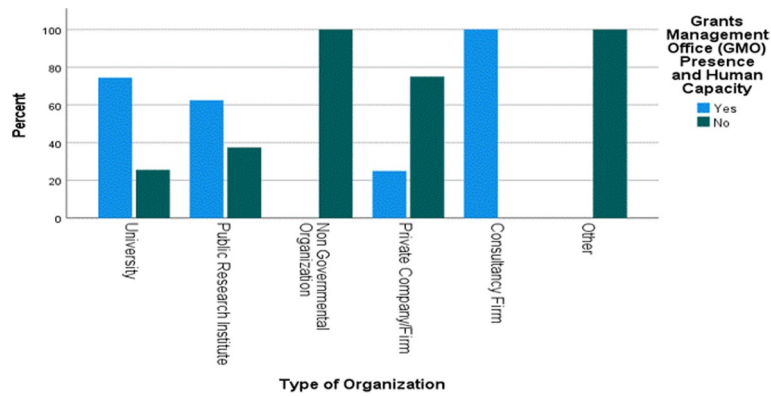
#### ***The presence of grants management offices***

Grants Management Offices (GMOs) are crucial in the process of commercializing innovative ideas and provide support for securing grant financing and administration, thus facilitating the growth of innovative ventures (Acebo & Miguel-Dávila, 2024; Zhu et al., 2020). With their guidance, inventors can navigate the complexities of commercialization, increase their chances of obtaining funding, and expedite the process. GMOs contribute to the successful transformation of ideas to commercial products by maintaining compliance, tracking progress, and promoting strategic alliances.

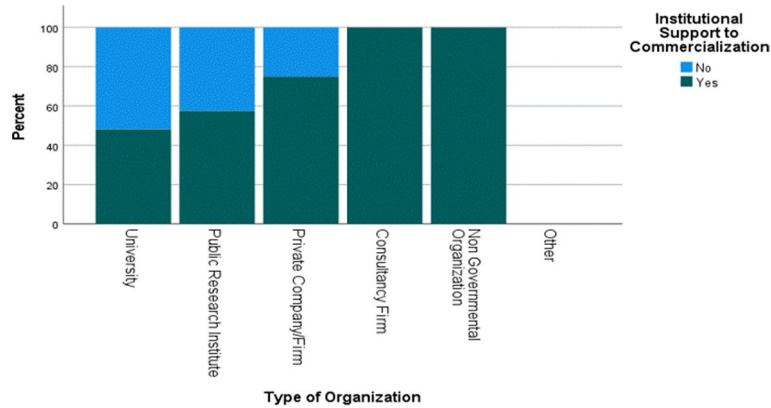
Figure 13 illustrates that all consulting businesses (100%), certain colleges (76%), and research institutions (62%) have established grant management offices (GMOs) to manage their funding resources. By contrast, NGOs are less likely to have GMOs, as they frequently receive financing from parties whose agendas they advocate. Consequently, having a GMO may not be a priority for these organizations, as they do not require funding from external sources to support their activities.

#### ***Allocation of resources for institutional innovation and commercialization***

Institutional innovation and commercialization require significant resources to promote economic growth, job creation, technological transfer, and cooperation;



**Fig. 13** Presence of grants management offices in organizations



**Fig. 14** Institutional allocation of resources for commercialization

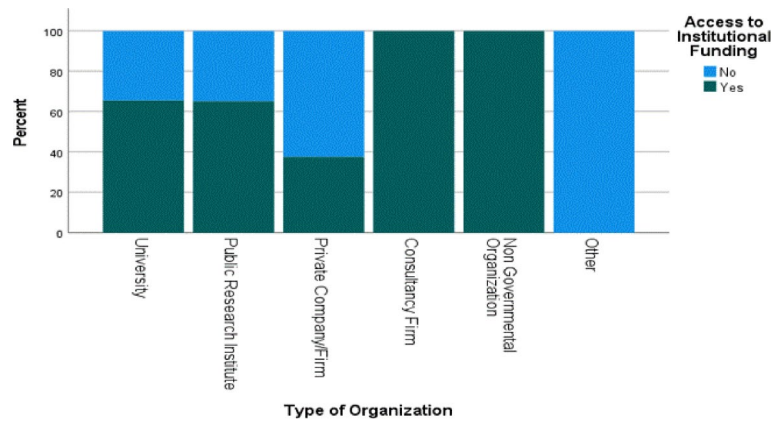
address social concerns; generate income; and enhance institutional reputation (World Bank, 2021; Zhu et al., 2020). By fostering an innovative culture and encouraging entrepreneurship, these efforts contribute to society’s general prosperity and advancement.

Most participating R&I institutions, except for certain universities (52%), research institutes (42%), and private enterprises (25%), reported committing resources to support commercialization efforts (Fig. 14). These institutions primarily consisted of private and research organizations that aimed to generate revenue through education and training by committing resources to support commercialization efforts.

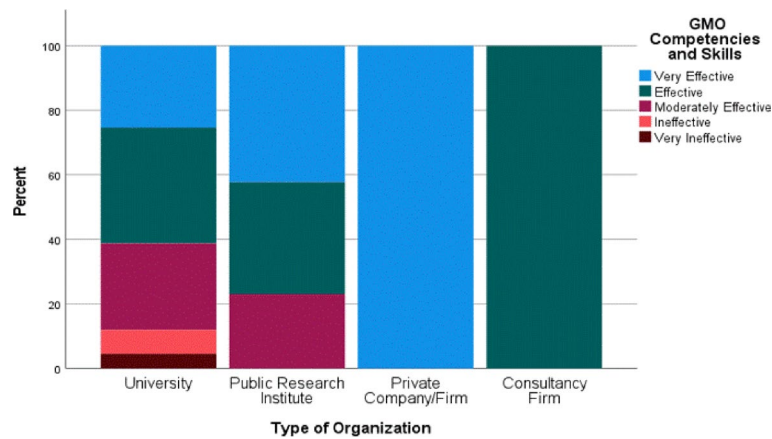
***Accessibility to the available resources for innovation and commercialization***

According to Hogan et al. (2022) and Zhu et al. (2020), the availability of accessible resources is of the utmost importance for securing finance, acquiring knowledge, utilizing infrastructure, developing connections, protecting intellectual property, validating market viability, and adhering to regulatory guidelines. These resources are vital for ensuring the successful commercialization of inventions.

Based on the survey results, access to financing was generally robust at universities, research institutes, consulting firms, and non-governmental organizations (Fig. 15).



**Fig. 15** Presence of institutional funding mechanisms for research and innovation



**Fig. 16** Grants management office competencies and skills

Additionally, private firms reported more negative than positive responses regarding access to institutional funding for R&I.

**Level of skills and competencies at grants management offices**

The efficacy of the grants management office (GMO) depends on the possession of adequate abilities and competencies. Grant management encompasses the administration and control of grant programs, including application processing, fund disbursements, project monitoring, and compliance with grant criteria (Agostino et al., 2020; Zhu et al., 2020). It ensures efficient administration, regulatory compliance, effective risk management, project result evaluation, stakeholder participation, financial management, understanding of the financing landscape, and continuous development. The presence of competent experts in grant programs can lead to more significant impacts and better social, economic, and environmental outcomes.

Figure 16 illustrates the proficiencies and abilities of grants management offices (GMOs) in aiding institutions with research and commercialization support. The survey results indicated that GMOs in private enterprises were highly effective, followed by research organizations (43%) and universities (24%). Private firms’ effectiveness

with GMOs is attributed to their strong emphasis on maximizing revenue in their commercialization efforts.

**Contextual analysis of the systemic, infrastructural, and financial drivers and barriers**

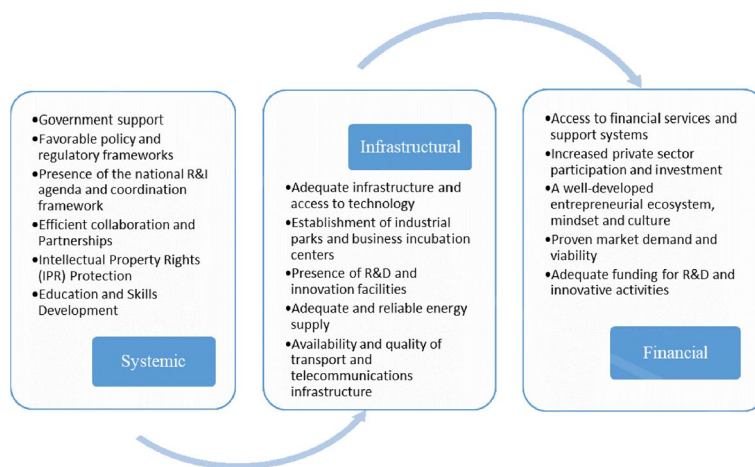
Innovation and commercialization play crucial roles in driving economic growth and development (Abbas et al., 2019; Kruachottikul et al., 2023). However, several factors can either support (drivers) or impede (barriers) innovation and commercialization at the institutional level, as highlighted by Perry (2020), which are explored in the systemic, infrastructural, and financial contexts (Fig. 17).

**Systemic drivers and barriers to innovation commercialization in Uganda**

Systemic drivers are significant elements within the broader research and innovation ecosystem that exert a profound influence on commercializing breakthroughs. According to Fashina et al. (2018) and Yang et al. (2022), these factors can impact the overall market conditions and either facilitate or impede the successful introduction and acceptance of new products, services, or technologies. Addressing and overcoming these systemic drivers and obstacles is crucial for organizations and policymakers seeking to create an environment that fosters the successful commercialization of innovations. By comprehending and leveraging these drivers and obstacles, stakeholders may enhance their prospects of bringing revolutionary ideas to the market and reaping associated economic and societal benefits. These include the following.

**Government support**

The Government of Uganda (GOU) plays a critical role in promoting innovation and commercialization by crafting regulations and policies that create a conducive business environment (Nahikiriza, 2023). The GOU implemented various programs and initiatives aimed at encouraging innovation and entrepreneurship, including financial incentives, supportive business climates, and the establishment of innovation hubs



**Fig. 17** Systemic, infrastructural, and financial drivers that influence the commercialization of innovations (Source: Authors)

and incubators. The government provides financial and technical support to creative companies through grants, subsidies, tax breaks, and R&D financing (Atwine et al., 2023). Public organizations in Uganda, such as the Uganda Development Bank (UDB) and the Uganda National Council for Science and Technology (UNCST), offer financial and technical assistance to support commercialization efforts, as indicated by (NPA, 2020). The GOU needs to foster an environment that nurtures the success of innovators and entrepreneurs by offering incentives, such as tax cuts, grants, and subsidies.

#### ***Favorable policy and regulatory frameworks***

It is of utmost importance that policy and legal frameworks be established to promote the commercialization of groundbreaking innovations. This requires the implementation of comprehensive and supportive legislation, robust intellectual property protection, streamlined business registration processes, and R&D incentives. According to Nahikiriza (2023), such measures are essential to enable innovators to bring their ideas to fruition. Governments can further encourage the commercialization of breakthroughs through initiatives such as offering tax breaks for R&D, providing innovation grants, and implementing public procurement programs that prioritize innovative solutions. Governments play a crucial role in fostering an environment that encourages investment, risk-taking, and entrepreneurship.

#### ***Presence of the national R&I agenda and coordination framework***

The allocation of resources for R&D is a crucial component in determining the success of innovation and is shaped by a country's national R&I agenda and coordination structure (Schwab & Zahidi, 2020; Sithole, 2020). Both government and corporate sectors must prioritize R&D to encourage the development of innovative ideas, products, and services (Hogan et al., 2022). The availability of funding for experimental R&D is a critical factor in determining the success of innovation; therefore, the Ugandan government, in collaboration with development partners, should invest more resources in R&D to foster innovation and commercialization.

#### ***Efficient collaboration and partnerships***

Collaboration among various stakeholders, including the government, academia, business, and international organizations, is crucial for fostering the commercialization of innovations. Partnerships enhance the likelihood of successful commercialization by facilitating information exchange, resource mobilization, and market access. Public private partnerships (PPPs) are vital in boosting innovation, productivity acceleration, and commercialization in Uganda by leveraging the capabilities and links between the public and private sectors (Salmon et al., 2020; Sendawula et al., 2023). The government can collaborate with private sector enterprises to fund and provide expertise for new initiatives involving partnerships between existing corporations and startups, as well as investments from both domestic and foreign companies. The private sector's involvement not only provides financial resources, but also knowledge, networks, and market access, which accelerates the commercialization process. To support R&D, the private sector can provide funds and investments, whereas the government can offer grants and subsidies. This contributes to an environment that fosters both creativity and

entrepreneurship. Uganda's engagement in regional and international trade agreements and partnerships enables access to larger markets, attracts foreign investment, and promotes knowledge transfer, resulting in the commercialization of innovations.

#### ***Intellectual property rights (IPR) protection***

Intellectual property rights (IPR) play a crucial role in encouraging innovation and creativity by protecting inventors' ideas and innovations against unlawful use or replication (Pererva et al., 2024). A strong legal framework for patents, trademarks, copyrights, and other forms of intellectual property protection fosters an environment conducive to the commercialization of inventions, thereby promoting economic growth and development. Uganda has been striding to strengthen its intellectual property rules and regulations, which has helped build confidence among inventors and attract investment. The national IP policy addresses various essential issues, including IPR enforcement and IP commercialization, and the implementation of the IP strategy requires increased human and financial resources (MOJCA, 2019). Policymakers must continue to emphasize the importance of IPR in driving innovation, transformation, and growth.

#### ***Education and skills development***

Uganda's education and research systems play a pivotal role in fostering innovation and commercialization (Tweheyo et al., 2024). The development of a skilled workforce and the cultivation of entrepreneurial talent are of utmost importance for the commercialization of innovations. The Government of Uganda (GoU) and educational institutions are making concerted efforts to enhance science, technology, engineering, and mathematics (STEM) education and establish training programs for entrepreneurship. By investing in R&D, the country may uncover new technologies, develop new products and services, and create new commercialized business models (Lenihan et al., 2023). Collaboration among the government, universities, and other research organizations is essential for creating an environment that promotes innovation and commercialization.

#### **Infrastructural promoters and challenges to innovation commercialization in Uganda**

Infrastructure drivers who contribute to the successful commercialization of innovations are fundamental elements of a supportive infrastructure. These drivers play a crucial role in creating an environment that fosters the growth, adoption, and diffusion of innovative technologies, goods, and services in the market. R&I infrastructure is essential for facilitating the entire process of transforming an idea into a commercial product (Kwesiga, 2019; Ogwang & Vanclay, 2021; Pius & Owin, 2024). These infrastructure components are interrelated and mutually reinforcing, promoting an environment conducive to innovation and supporting the successful commercialization of innovative ideas, technologies, and products in the marketplace. These include the following:

#### ***Adequate infrastructure and access to technology***

Infrastructure is a crucial element of innovation and commercialization in any country. In Uganda, transportation and energy infrastructure are of utmost importance in facilitating innovation and commercialization. Uganda has made commendable progress

in modernizing its infrastructure, including transportation, communication networks, and electrical availability (Ogwang & Vanclay, 2021; Pius & Owin, 2024). The increasing use of mobile phones and Internet access has also opened opportunities for technological advancement. However, the country's transportation infrastructure remains insufficient with limited rail links and inadequate road networks. Enhancing transportation and logistics can help businesses operate more efficiently by facilitating the movement of goods and services across the country, thereby lowering costs and improving efficiency.

#### ***Establishment of industrial parks and business incubation centers***

The establishment of industrial parks and business incubators has a positive impact on the commercialization of ideas. Studies by Kwesiga (2019) and Atwine et al. (2023) indicate that these facilities offer shared infrastructure, including cost-effective office spaces, labs, testing facilities, and manufacturing units, which can aid entrepreneurs and innovators in reducing expenses. A robust technical infrastructure is crucial for the commercialization of inventions, encompassing access to advanced technologies, ICT systems, high-speed Internet connectivity, and digital platforms that support multiple stages of the innovation process, including research, development, manufacturing, marketing, and sales.

#### ***The presence of R&D and innovation facilities***

The existence of R&D facilities, universities, and research institutes supports the commercialization of innovations by fostering an environment of information sharing and technological growth through collaboration among academics, inventors, and entrepreneurs (Bowman, 2019; Pius & Owin, 2024). Academic institutions, research groups, and private enterprises are all actively engaged in R&D, resulting in the creation of new technologies and solutions that can be commercialized. The support and resources provided by institutions and organizations that support inventors and entrepreneurs, such as company incubators, technology transfer offices, innovation centers, research institutes, industry associations, and networks that offer mentorship, training, market information, and business development services, are crucial for commercialization success.

#### ***Adequate and reliable energy supply***

Reliable power availability is of the utmost importance for businesses, particularly those that rely on technology and industry (Bakhtiar et al., 2020). Access to dependable and affordable electricity enables developers to test innovative technology, power critical machinery, equipment, and technological devices utilized in many companies and minimize operating expenses while enhancing productivity. Although Uganda has made significant progress in expanding its access to electricity in recent years, more effort is necessary to ensure a continuous and affordable power supply (Fashina et al., 2018).

#### ***Availability and quality of transport and telecommunications infrastructure***

Transport infrastructure plays a vital role in the delivery of goods and services, and well-developed road networks, trains, ports, and airports are critical for product transportation to local and global markets (Bakhtiar et al., 2020; World Bank, 2018). An

improved transportation infrastructure can minimize logistical obstacles, reduce costs, and improve market access to new products. A study by Bowman (2019) indicated that communication technology is also essential for both invention and commercialization, and access to information about new ideas, goods, and services is made possible through communication technology. Dependable and economical communication networks are necessary to support e-commerce platforms, digital transactions, and distribution of information. Entrepreneurs and innovators may use the internet to learn about global trends, R&D, and best practices. While Uganda has made considerable progress in expanding its mobile and Internet networks, more work needs to be done to ensure that these technologies are available to all Ugandans, particularly those living in rural regions.

#### **Financial incentives and constraints to innovation commercialization in Uganda**

According to the World Bank (2021), financial incentives for innovation commercialization are crucial elements that determine the success or failure of transforming creative ideas or technologies into profitable products or services. These components are integral to the financial aspects of commercialization and are inseparable from the process. The interaction between financial drivers and non-financial elements, such as technical readiness, market demand, regulatory environment, and organizational skills, significantly impacts the success of innovation commercialization initiatives. These include the following.

#### ***Access to financial services and support systems***

Entrepreneurs and innovators require funding from well-functioning banking systems, venture capital firms, investors, and microfinance organizations. Adequate financing is necessary for entrepreneurs and inventors to convert their ideas into commercially viable goods and services (Omri, 2020; Varaksa et al., 2021). Financial institutions, venture capitalists, investors, and crowdsourcing platforms can finance R&D, prototype development, scaling-up manufacturing, marketing, and other commercialization operations. The financial industry in Uganda is underdeveloped, with limited access to loans and a low degree of financial literacy (NPA, 2020; World Bank, 2021). A strong financial system that fosters startups and small businesses is necessary in Uganda. The government can help by enacting regulations that make it easier for entrepreneurs to obtain funding as well as by providing grants and loans to promote new ideas and encourage venture capitalists and investors to invest in local firms.

#### ***Increased private sector participation and investment***

Typically, investors and stakeholders are concerned with the prospective return on their investments. The capacity of an innovation to produce a financial return and provide a competitive advantage significantly impacts its chances of commercialization. A comprehensive business plan accompanied by a compelling financial projection outlining the predicted return on investment (ROI) can attract investors and facilitate the commercialization process. Entrepreneurs and inventors require access to venture capital to commercialize their ideas (Stubbs et al., 2022; World Bank, 2021). To foster an environment that encourages venture capital firms to participate in Ugandan

start-ups and techno-business ventures, Uganda's government and the private sector should collaborate. To encourage investors to invest in innovative ventures in Uganda, the government can offer tax incentives such as breaks, holidays, and reduced tax rates. These incentives encourage investors to engage in creative initiatives.

#### ***A well-developed entrepreneurial ecosystem, mindset, and culture***

It can be stated that Uganda's social and cultural structures have the potential to foster innovation and commercialization. Uganda's entrepreneurial attitude and culture are growing and providing a supportive climate for the commercialization of ideas (Okumu & Buyinza, 2020; Salmon et al., 2020). Many individuals embrace entrepreneurship and take risks in creating and promoting novel products and services. Entrepreneurship should be recognized as a legitimate career option, and society should acknowledge and reward inventors and entrepreneurs who generate employment and drive economic progress. The commercialization of ideas can be facilitated by a well-developed entrepreneurial ecosystem, which includes incubators, accelerators, mentorship programs, and networking platforms. These mechanisms can connect entrepreneurs to expertise, business development resources, and potential investors, helping them navigate the financial challenges of commercialization.

#### ***Proven market demand and viability***

The commercial success of an innovation is predicated on its market demand and feasibility. Innovators must demonstrate the economic viability of their goods and services, including market size, consumer preferences, competitive advantages, and revenue generation potential. Studies show that it is imperative to understand the target market's demands and preferences to achieve successful commercialization of inventions (Ajer et al., 2023; Sendawula et al., 2023). Ugandan entrepreneurs are increasingly focusing on developing products and services that cater to the local market. The size of the target market and its potential for expansion are critical considerations for investors and organizations seeking to commercialize inventions. A larger market with strong growth potential provides an attractive proposition for commercialization, offering opportunities for better profits and increased scalability.

#### ***Adequate funding for R&D and innovative activities***

Adequate financing for R&D activities is crucial for creating commercially viable ideas and prototypes. R&D activities can be supported by funding from government agencies, research institutes, universities, and international organizations, enabling inventors to produce commercially viable solutions. Uganda has seen an increase in both local and foreign investment prospects, with the government and private investors providing financial support to startups and innovative initiatives (Sendawula et al., 2023; World Bank, 2021). To further encourage these activities, the government, in collaboration with the private sector, should support R&D, establish a favorable climate for venture capital, provide tax breaks, promote public private partnerships (PPP), and guarantee that appropriate rules and regulations protecting intellectual property rights (IPRs) are in place.

### **Recommended strategies to overcome the systemic, infrastructural, and financial barriers**

Improving systemic coordination within the R&I ecosystem can not only reduce ecosystem fragmentation, but also enhance the efficiency of infrastructural investments and financial resource allocation. A holistic policy approach that simultaneously addresses systemic coordination, infrastructure development, and financial support mechanisms is crucial for closing the existing gaps.

### **Strategies to overcome systemic barriers to innovation commercialization**

Firms and policymakers must recognize and tackle systemic obstacles that hinder the commercialization of innovations to foster an environment that encourages the application of creative ideas. To address the fundamental challenges faced by the research and innovation sector, a comprehensive strategy encompassing multiple policies and approaches must be employed to overcome the interrelated systemic hurdles, as highlighted by Fashina et al. (2018) and Perry (2020). The following measures and actions are recommended to overcome these systemic gaps.

#### ***Develop regulatory frameworks***

It is imperative that the government establish regulatory structures that foster research and innovation, including regulations that encourage public private partnerships, protect intellectual property rights, and support inventors by providing a conducive operating environment.

#### ***Enhancing collaboration between academia and industry***

The connection between academia and industry must be reinforced to promote innovation and technology transfer. This can be achieved by inviting industry to participate in R&D, creating technology transfer offices within universities and research institutes, and promoting collaborative research initiatives between academia and industry. These collaborative efforts may take the form of joint research projects, internships, and exchange programmes. By fostering these relationships, technology and knowledge can be more effectively transferred between the two sectors, leading to increased innovation and commercialization.

#### ***Strengthening Intellectual Property Rights (IPRs) protection***

The enactment of more stringent rules and regulations by the government can significantly enhance the protection of Intellectual Property Rights (IPR). This measure will help safeguard the intellectual property of creative startups and small enterprises, which, in turn, will attract additional investors to the industry in the long run. The implementation of laws that promote the creation, protection, and commercialization of intellectual property as well as the establishment of an effective patent registration and enforcement system will facilitate this process.

#### ***Skills development and capacity building***

Uganda must invest in capacity-building initiatives to equip researchers and innovators with the requisite skills and knowledge to thrive in an innovation ecosystem. This

can be achieved through training and mentorship programs, encouragement of international collaboration, and support for the development of professional networks. The curricula for such programs may encompass training in research methods, scientific communication, grant proposal writing, intellectual property rights, and entrepreneurship, among others.

#### ***Providing training and mentorship***

The utilization of formal training and mentorship programs by government entities may be advantageous for startups and small businesses because it allows students to acquire the expertise and information necessary to effectively promote their innovative notions. The removal of structural barriers in Uganda necessitates a protracted dedication to policies and processes that foster collaboration, creativity, and technology transfer.

#### **Strategies to overcome infrastructural challenges to innovation commercialization**

An effective support infrastructure is imperative for the transition of innovative ideas to market-ready solutions. To address the infrastructural challenges in Uganda, a thorough strategy comprising of diversified tactics and policies must be implemented (Kwesiga, 2019; Pius & Owin, 2024). To address the infrastructure gaps in the commercialization of inventions at research and innovation institutions, the following methods and actions are proposed:

#### ***Improved access to advanced technology***

The government must forge partnerships with developed nations to acquire cutting-edge technologies that can contribute to R&I. In addition, the creation of scientific parks and technology centers can foster an environment that encourages innovators to utilize these new technologies.

#### ***Strengthening R&D and innovation institutions***

Uganda must prioritize the establishment of well-equipped R&D institutions that can engage in effective collaboration and knowledge sharing. To achieve this, a country should increase its investment in R&D, forge partnerships across institutions, and promote interdisciplinary research.

#### ***Enhancing infrastructure and technology transfer***

Uganda must allocate resources to improve the infrastructure necessary to promote innovation and technology transfers. This includes the creation of data- and information-sharing networks, the establishment of technological parks and centers of excellence, and the implementation of platforms for knowledge exchange and cooperation.

#### ***Improving communication and dissemination of research***

The promotion of open-access repositories for the dissemination of research and innovation findings is a matter of great importance. Such repositories, in conjunction with forums for the exchange of information between academics and innovators, can enhance communication and foster cooperation. Therefore, the government must support the establishment and maintenance of these resources.

**Strategies to overcome financial constraints to innovation commercialization**

The correlation between financial obstacles and the financial aspects of the commercialization process is substantial and has a significant impact on the market outcome of innovation. Studies indicate that overcoming financial challenges necessitates the implementation of a range of initiatives and policies that address a country's core issues (Sendawula et al., 2023; World Bank, 2021). The following policies and approaches are recommended to overcome financial gaps.

***Establishment of specialized innovation financing institutions***

To provide financial support to creative startups and small enterprises, the government can establish specialized innovation financing entities such as venture capital firms, angel investor networks, and innovation funds. These organizations can offer various forms of financing, including seed investment and venture capital, to assist businesses in commercializing their unique ideas.

***Promoting entrepreneurship and innovation***

Uganda must create an enabling environment for entrepreneurship and innovation by ensuring access to finance, providing support for incubation centers and innovation hubs, and implementing regulations that foster entrepreneurship and innovation.

***Increased funding for research and innovation***

The government of Uganda must augment its financial support for research and innovation to foster the development of critical infrastructure, establish centers of excellence for research, and provide grants to innovators. Given the critical barrier to insufficient innovation financing identified in our findings, we propose the establishment of a national innovation fund as a direct countermeasure to enhance the availability of financial resources for R&I institutions.

***Providing tax incentives***

The government should offer tax incentives to investors who invest in innovative startups and small enterprises. This initiative would encourage greater private investment in research and commercialization, thereby fostering the growth of Uganda's innovation ecosystem.

***Promoting access to finance***

Through the implementation of credit guarantee schemes, reduced collateral requirements, and simplified loan application processes, governments may enhance access to capital for startups and small businesses. This could result in more startups and small businesses obtaining financing, leading to increased innovation and commercialization.

The findings provide valuable insights into the systemic, infrastructural, and financial drivers and barriers that impact the successful commercialization of innovations at R&I institutions in Uganda. Such knowledge is essential for the formulation and implementation of inclusive innovation and commercialization policies (Fashina et al., 2018; Nahikiriza, 2023). Moreover, R&I institutions can utilize the study's results to

establish and enhance connections and collaborations with one another. Additionally, the study adds to the existing body of knowledge on the commercialization of innovations using an integrated systemic, infrastructural, and financial approach in developing countries, particularly in Africa, where limited research has been conducted in this area.

## Conclusion

### Theoretical implications

While the Triple Helix model emphasizes the role of university-industry-government collaborations in fostering innovation ecosystems (Noya & Taneo, 2023; Zhuang et al., 2021), this study's findings on the fragmentation of the R&I ecosystem in Uganda and inadequate support infrastructure highlight a critical gap in the model's applicability to developing countries. Specifically, the study reveals a disconnection between policy intentions and on-the-ground realities, suggesting that the Triple Helix model may need adjustments to reflect the challenges faced in these contexts more accurately.

Moreover, findings on financial barriers, including reliance on external funding and the lack of a national research fund, point to a significant gap in the literature on financing innovation in developing countries (Moon, 2022; Salmon et al., 2020). This study contributes to theoretical understanding by illustrating the complexities and challenges of securing sustainable financing for innovation in environments where government support may be inconsistent and external funding sources play a dominant role. These insights could inform the development of new theoretical frameworks or the refinement of existing models to better account for the financial realities of innovation commercialization in similar settings. Currently, there is no formal mechanism for funding long-term research and innovation because of the government's shifting priorities and absence of an approved framework for innovation and research.

Tweheyo et al. (2024) indicate that institutional elements play a crucial role in university commercialization processes, with an emphasis on patent policies, revenue distribution systems, and entrepreneurial education for researchers. This perspective aligns with the work of Min et al. (2020), which emphasizes the significance of TTOs in enhancing commercialization success rates at research universities through appropriate organizational structures and entrepreneurial initiatives. Namugenyi et al. (2023) presents an alternative viewpoint by examining the potential adverse effects of innovation, specifically how the implementation of biomass technology innovations may lead to the erosion of traditional cooking practices, thereby affecting the subjective well-being of households. This insight underscores the necessity of considering socio-cultural contexts in the commercialization process, as innovations may have unanticipated consequences on societal norms and customs.

The conceptual implications suggest that the effective commercialization of innovations within Uganda's research and innovation sectors necessitates a comprehensive strategy. Critical factors contributing to success include institutional elements, such as conducive policies and frameworks, entrepreneurship education, and the role of TTOs (Tweheyo et al., 2024). Furthermore, it is imperative to assess the societal and cultural implications of innovation, as these factors can influence public acceptance and overall well-being (Namugenyi et al., 2023). These findings enhance

our understanding of the commercialization process and identify areas for further investigation and policy development (Namugenyi et al., 2023; Tweheyo et al., 2024).

### **Policy implications**

Policies must address knowledge gaps in understanding the specific regulatory barriers that most significantly impede the commercialization process, such as stringent intellectual property laws that deter rather than encourage innovation. There is a critical knowledge gap in identifying which R&D infrastructural elements most significantly enhance commercialization outcomes, necessitating targeted studies to inform infrastructure development policies (Nahikiriza, 2023; Pius & Owin, 2024). Policies must be informed by a deeper understanding of the factors that motivate or deter private sector investment in R&I, particularly in developing countries, such as Uganda, where economic conditions differ significantly from those in developed economies.

A significant knowledge gap exists in identifying effective and sustainable financing models for innovation that combine government funding, private investment, and international partnerships (Salmon et al., 2020; Sendawula et al., 2023). Future policies should be informed by research into successful models in similar economies. There is a need for empirical research on the most effective mechanisms for implementing innovation policies in Uganda, including stakeholder engagement strategies, policy communication, and the role of intermediaries in bridging the gap between policymakers and R&I institutions. Policymakers and stakeholders must strengthen the legal and regulatory framework for innovation, intellectual property protection, and commercialization and ensure effective enforcement of existing restrictions to enhance the R&I ecosystem in Uganda.

The research conducted by Tweheyo et al. (2024) emphasizes the importance of institutional factors, including patent policies, revenue-sharing frameworks, and the necessity of developing entrepreneurial skills among researchers. These elements play a crucial role in enhancing the commercialization of university research outputs. Similarly, Onapa et al. (2020) and Nahikiriza (2023) highlight the significance of well-coordinated STI policies among various stakeholders. They suggest that political commitment and initiatives such as the Millennium Science Initiative can foster innovation. However, challenges have been identified, including the absence of a cohesive system for STI policy coordination and the underdeveloped state of technology advancement and commercialization within academic institutions.

Namugenyi et al. (2023) elucidated the unanticipated negative consequences of biomass technology innovation on the perceived well-being of Ugandan households. This finding underscores the significance of policymakers, considering both the advantages of bioenergy advancements and the welfare of those utilizing technology. This further emphasizes the necessity for policies that achieve equilibrium between technological progress and sociocultural values. For efficient innovation commercialization in Uganda, policymakers should prioritize establishing supportive institutional structures, enhancing researchers' entrepreneurial capabilities, and ensuring well-coordinated STI policies (Onapa et al., 2020; Tweheyo et al., 2024). Moreover, policies should aim to foster an environment that facilitates collaboration between the public and private

sectors, while addressing the specific requirements and challenges encountered by research and innovation institutions within the country.

### **Ideas for future research**

Future research should focus on developing an empirical framework for measuring the direct impact of private sector collaboration on innovation commercialization success in Uganda. This could help in designing targeted interventions that leverage private sector strengths for R&I commercialization (Stubbs et al., 2022). Future research could focus on identifying effective models for public private partnerships in the R&I ecosystem that enhance commercialization outcomes in Uganda. This would not only highlight a knowledge gap but also direct future research towards a critical area that could support the commercialization process.

Based on the noted challenge of financing long-term research and innovation due to shifting government priorities, future research could investigate how fluctuations in government support impact the sustainability of long-term research and innovation projects in Uganda, and what alternative financing models can ensure their continuity (Ali et al., 2023; Varaksa et al., 2021). The role of digital transformation in enhancing the commercialization process at R&I institutions in Uganda, and a comparative analysis of the commercialization process in R&I institutions across East African countries could potentially be explored. While Uganda has made notable progress in fostering an R&I environment that promotes innovation and commercialization, there is still room for improvement. Uganda offers numerous opportunities for enhanced research and innovation. The growing demand from stakeholders necessitates the fortification of institutional capacity through the implementation of novel models of institutional transformation and growth, which requires further research.

Research suggests that the commercialization process is significantly influenced by a combination of internal and external elements, as well as the specific innovation context (Musabayana et al., 2023; Palinkas et al., 2023; Shcherbachenko & Kotenko, 2022). Several studies have identified broad obstacles, such as transaction expenses, institutional management, and uncertainties related to innovation (Kavaarpuo, 2022). Conversely, others have focused on sector-specific factors, including the impact of social influences and behavioral regulation in healthcare (van der Zanden et al., 2024), and environmental and organizational challenges in the mining industry (Ediriweera & Wiewiora, 2021). Furthermore, researchers have emphasized the importance of examining the interplay between obstacles, facilitators, and various innovation outcomes (Stornelli et al., 2021).

Future research endeavors should focus on developing a comprehensive model that integrates diverse perspectives and addresses the specific challenges faced by Ugandan research and innovation entities. This model should encompass industry-specific barriers and facilitators, the influence of organizational leadership, and the impact of societal and psychological factors on innovation adoption (Pius & Owin, 2024). Furthermore, the role of technological advancements in the commercialization of innovations such as Cloud ERP merits further investigation (Ali et al., 2023). Research methodologies can be enhanced through the application of theoretical frameworks, including the theoretical domain framework (van der Zanden et al.,

2024), to systematically examine the relevant factors. Ultimately, the research findings should inform the development of targeted strategies to overcome identified barriers and leverage enablers for successful innovation commercialization in Uganda.

### Limitations of the study

While this study provides in-depth insights into the Ugandan context, it acknowledges the limitations in its applicability to other developing countries without considering their unique socio-economic, regulatory, and technological landscapes. Future research could expand this study's framework to other contexts to validate the universality of identified drivers and barriers. This study's cross-sectional design limits its ability to capture the dynamic nature of innovation commercialization barriers and drivers over time. Longitudinal research is recommended to understand how these factors evolve in response to changes in the national and global economic conditions.

Despite utilizing a mixed-methods approach, this study recognizes the limitations in the depth of the qualitative insights obtained. Future research could employ ethnographic or detailed case studies to delve deeper into the personal experiences and challenges faced by innovators and policymakers in Uganda. This research acknowledges the limitation of capturing the full spectrum of stakeholder perspectives within Uganda's innovation ecosystem, particularly from end-users and the informal sector. Future studies should aim to include these voices to provide a more comprehensive view of the commercialization landscape.

### Abbreviations

BFP	Budget framework paper
GERD	Gross expenditure on research and development
EDIC	Engineering Development and Innovation Center
GDP	Gross Domestic Product
GMO	Grants Management Office
GoU	Government of Uganda
ICT	Information and Communication Technology
IP	Intellectual property
IPMO	Intellectual Property Management Office
IPR	Intellectual property rights
ITDT	Innovation, technology development, and transfer
MDAs	Ministries, Departments and Agencies
MTEF	Medium-term expenditure framework
NDP	National Development Plan
NGO	Non-Government Organization
NIS	National innovation system
PPP	Public Private Partnership
R&D	Research and development
R&I	Research and innovation
RoI	Return on investment
SPSS	Statistical Package for Social Scientists
STEM	Science, Technology, Engineering and Mathematics
STI	Science, Technology and Innovation
STI-OP	Science, Technology and Innovation Secretariat-Office of the President
TT	Technology transfer
TTO	Technology transfer office

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### Author contributions

All authors contributed to writing the manuscript and read and approved the final manuscript. RJ and LA analyzed the datasets used for the study and drafted the manuscript, while JBK and NM reviewed and revised the manuscript.

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### Data availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

### Declarations

#### Competing interests

The authors declare no conflicts of interest.

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## **PAPER V**



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**Firm-specific, market-centric and policy-related determinants of ‘commercialization valley of death’ encountered by techno-business firms in Uganda**

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**Abstract**

Firms typically invest a significant portion of their resources in basic research to generate new ideas and technologies. However, turning these ideas into marketable products can be challenging, and firms often struggle to bridge the gap between prototype development and successful product commercialization. Although extensive research exists on the commercialization valley of death (CVD), the current literature lacks a comprehensive analysis of the intricate relationships between company-specific capabilities, market dynamics, and regulatory frameworks in developing nations such as Uganda. This study aims to examine and evaluate the various factors influencing CVD, with a particular emphasis on often-neglected firm-specific, market-oriented, and policy-related elements within Uganda's emerging techno-business sector. Utilizing a rigorous quantitative methodology, this study encompasses comprehensive interviews and observational studies of more than 50 techno-entrepreneurs in Uganda. Observations were made to understand the interactions and contextual factors associated with CVD. Interviews were conducted to gain insights and experience regarding the firm-, market-, and policy-related determinants of CVD. The results indicate that robust research and development (R&D) infrastructure and supportive government regulations are crucial factors. However, their effects are substantially influenced by market-related elements such as public awareness and the rate of adoption of new technologies. This demonstrates a complex network of interconnected factors that has not been thoroughly examined in previous studies. Bridging CVD hinges on sustainable financial systems, effective partnerships/collaborations, strong global linkages, and the availability of R&D infrastructure. This study contributes to the theoretical knowledge base by elucidating the complex factors influencing CVD in developing countries while also providing practical recommendations for policymakers. It proposes a multifaceted approach to enhancing innovation ecosystems, encompassing targeted support for R&D infrastructure, initiatives to facilitate market access, and modifications to regulatory frameworks. This would generate transformational development by increasing industrial output and strengthening the linkages between techno-business firms and the industrial sector.

**Keywords:** commercialization valley of death, firm-specific, market-centric, policy-related, techno-business firms, Uganda.



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### **Introduction**

The commercialization valley of death (CVD) refers to the gap between the development of new scientific knowledge and commercialization of new products (Huizingh & Biemans, 2020; Takata et al., 2022). Many firms face challenges in transforming their scientific research into marketable products and the transition from invention to innovation is a significant obstacle. Industry estimates suggest that four of the five new inventions never entered the market (Gbadegeshin, 2018; Kim et al., 2019). This is concerning, because inventions often represent a significant opportunity for the development and launch of radically new products. Further, firms invest substantial resources in the development of new technologies. However, resources can be wasted if these technologies are not commercialized.

The CVD concept has typically been viewed as the gap between basic research conducted by scientists and researchers, and product development conducted by firms (Upadhyayula et al., 2018; Takata et al., 2022). Although the concept of CVD has been well documented, the literature offers limited guidance on how to overcome this gap among researchers, innovators, and techno-business enterprises, or what role broader organizational factors play in this process. Most empirical studies on CVD in developing countries have not considered the entrepreneurial intentions of researchers, innovators, or techno-business enterprises (Al-Shaikh & Siddiqui, 2021; Lefebvre et al., 2022; Takata et al., 2022). However, given the current push to integrate economic development as a key function of research and innovation in these countries, these groups must operate more entrepreneurially.

Previous research has examined the role that governments, public institutions, and venture capital firms play in supporting innovation and bridging the funding gap associated with CVD (Lefebvre et al., 2022; Roca & O'Sullivan, 2022). However, research on CVD that occurs within the same firm, as opposed to other organizations, such as research institutions and techno-business enterprises, has been limited and has mostly focused on the role that individuals play in promoting projects for new product development. The lack of attention given to firm-specific factors that may facilitate or hinder the crossing of CVD is a significant limitation in prior research, and this study aims to address this gap.

The existing national innovation ecosystem in developing countries, such as Uganda, lacks linkages and interrelationships between various actors, and the connection between knowledge creators and users is insufficient (Guimón, 2013; Mulumba et al., 2017; Chaminade et al., 2018). To bridge this gap, researchers, innovators, and techno-business enterprises must go beyond generating useful knowledge and ideas. Instead, they must consciously work together to establish mechanisms that promote the commercialization of prototypes, inspire active involvement in designing marketable products, and assume leadership roles to ensure successful commercialization.

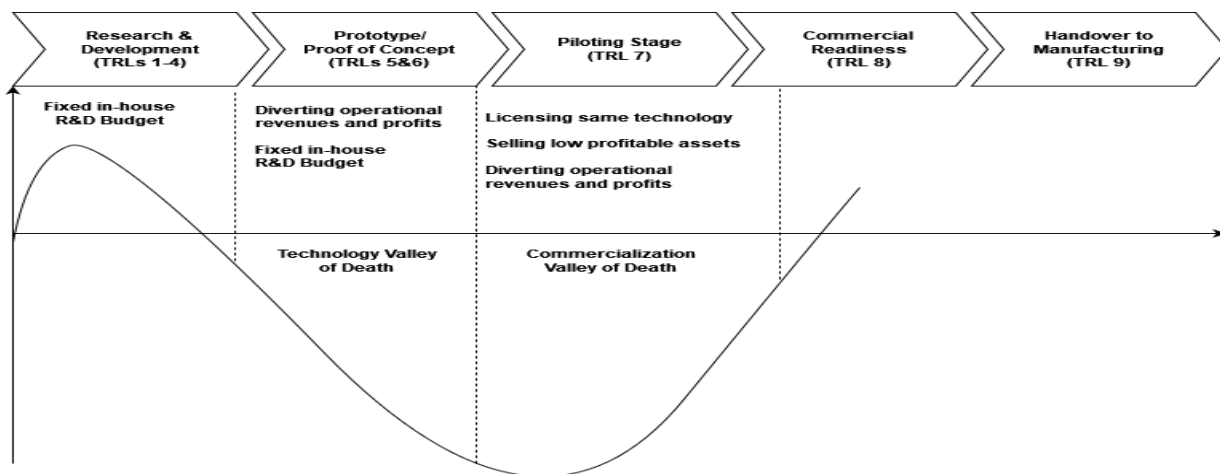
Although previous research has examined the influence of government support on innovation, there remains a significant gap in understanding how firm-specific elements, such as internal resource allocation and innovation management strategies, contribute to overcoming CVD in

Uganda. Moreover, the impact of market forces unique to developing economies on CVD has not been investigated thoroughly. With its emerging technological landscape, Uganda presents a distinctive opportunity to study CVD. In contrast to established markets, Ugandan techno-business firms encounter specific market-related challenges, including low consumer familiarity with novel technologies and a dynamic regulatory environment, which may exacerbate CVD. This study aimed to identify firm-specific, market-related, and policy-driven factors affecting CVD in Uganda, thereby addressing crucial gaps in the existing literature and providing valuable insights for policymakers and entrepreneurs to foster a more conducive environment for commercialization.

### Key empirical concepts

#### *Concept of commercialization valley of death*

CVD occurs during the early stages of science-based innovation, when a technology's continued development is impeded by a lack of funding and support. This phase has been described as occurring between the invention and innovation stages or between the technical invention or market recognition of an idea and the efforts to commercialize it (Ellwood et al., 2022; Huizingh & Biemans, 2020). It is also characterized as an inability to progress from the technology demonstration phase to the commercialization phase (Figure I). Although the terminology suggests that different innovation processes are important, this phase occurs at a critical juncture in technological development. The foundational scientific research activity has not yet been completed, and the commercialization of this technology is not yet fully understood. However, these two processes overlap and inform each other of each other.



**Figure I:** Technology and commercialization valley of death (Upadhyayula et al., 2018)

Technology transfer across this valley may pose significant management challenges (Dean et al., 2022; Son et al., 2022). It is widely accepted that the initial stages of science-based innovation are characterized by uncertainty regarding both technology and market understanding, and investment decisions are not always based on a secure foundation. The inherent organizational complexity of



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this development phase is contrasted with the two better-organized innovation functions that surround it, namely research and commercialization. The difference between these two functions is further exacerbated by the fact that they operate under different institutional logics, with science (research) and business (commercialization) having distinct normative and cultural logics. Therefore, managing the transition between these logics is crucial for preventing differences from becoming a barrier to the transfer of technological knowledge (Al-Shaikh & Siddiqui, 2021; Takata et al., 2022). For example, discrepancies in intellectual property-related cultural and normative logic can lead to conflicts in invention disclosure, patent licensing, and the ongoing use of intellectual property (IP) in their research.

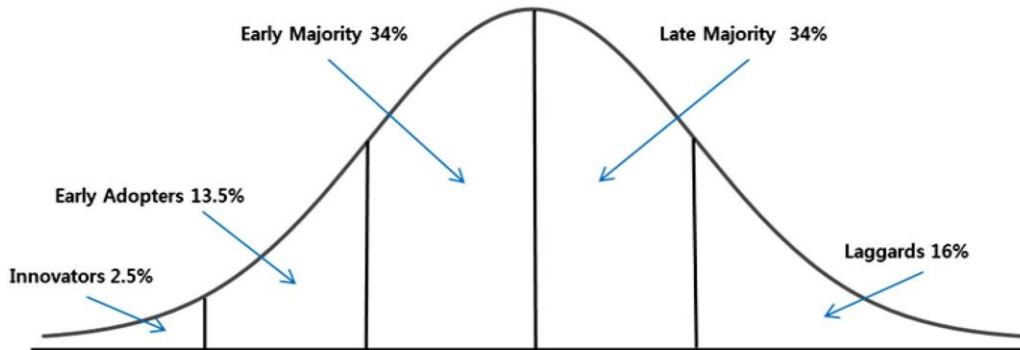
Although research on CVD is expanding, there remains a significant knowledge gap regarding the impact of firm-specific factors such as corporate culture and organizational structure on Ugandan techno-business firms' capacity to address CVD. Furthermore, the influence of market-oriented variables, including consumer readiness and product-market fit, within Uganda's specific context has not been thoroughly investigated. While the importance of technological proficiency and research infrastructure is recognized, there is limited understanding of how these elements interact with Uganda's distinctive market dynamics, such as consumer preferences for technological products and the target audience's digital literacy. This lack of comprehensive knowledge impedes the development of targeted strategies to overcome the CVD challenges in Uganda.

Furthermore, extant literature inadequately addresses the influence of policy-related factors, including governmental support for innovation and regulatory frameworks, on the commercialization process in contexts characterized by rapid policy changes and political instability, which are particularly pertinent to Uganda. This highlights a significant research gap that necessitates an examination of the relationship between firm-specific factors and the regulatory environment in Uganda as well as an investigation into the efficacy of various market penetration strategies for technology-based enterprises in overcoming CVD.

### *Technology adoption lifecycle*

The S-curve of technological innovation can be illustrated as a by-product that embraces new technology and aligns with the prevailing market trends. By dividing the technology lifecycle into the passage of time and the cumulative number of technological adopters on the vertical and horizontal axes (Figure II), respectively, we can better understand the curve (Byun et al., 2018; Kim et al., 2019).

According to Byun et al. (2018), innovators are the first to accept discontinuous innovation and represent approximately 2.5% of all consumers. Following this, early adopters or visionaries accepted innovation in the next stage, accounting for approximately 13.5% of all adopters. The early majority, or pragmatists, who are at the second highest level, tend to accept innovation slightly ahead of ordinary people in society, constituting approximately 34% of all adopters. The late majority, or conservatives, constituted the next highest proportion, accounting for approximately 34% of all adopters.



*Figure II: Technology adoption lifecycle (Byun et al., 2018)*

Lastly, laggards or skeptics, who are highly skeptical about innovation, account for approximately 16% of all adopters. The technology adoption cycle suggests that technological innovation does not have an immediate positive effect on the market and consumers and that it takes time to encourage the adoption of products, technologies, or ideas with discontinuous innovation, which is often associated with uncertainty and risk (Byun et al., 2018; Kim et al., 2019).

## Method

### *Study design and approach*

A quantitative research method was employed using interviews and observational approaches. This method involves gathering evidence through observations and interviews with techno-business entrepreneurs. Observations were made to understand the interactions and contextual factors associated with CVD. Interviews were conducted to gain insights and experience regarding the firm-, market-, and policy-related determinants of CVD. This allowed researchers to gain a deeper understanding of CVD by examining real-life conditions. This method enables researchers to interpret their findings and is highly relevant to empirical studies based on observations or experience (Holliday, 2014; Manly, 2015).

### *Study population*

A total of 55 participants were selected using purposive sampling based on their in-depth knowledge of the commercialization processes in Uganda. The study determined a participant count of 55 through power analysis, ensuring a 95% confidence level and a 5% error margin for quantitative data. For qualitative information, data collection continued until theme saturation was achieved with no novel concepts emerging from the interviews. Interviewees were selected based on their organizational positions (such as CEOs and R&D managers) and their firms' stages in the commercialization process (including the pre-commercialization, commercialization, and post-commercialization phases). Observations have focused on techno-business sector firms because of their significant relevance to the Ugandan market. The participant pool included techno-business entrepreneurs involved in the commercialization process of their enterprises. Key informants with experience and the ability to provide detailed descriptions of the commercialization process within



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their respective firms were chosen. All participants provided informed consent before participation.

### ***Data collection***

Data for this study were collected through interviews and observations of commercialization trends. This study employed a semi-structured interview methodology, focusing on three primary domains: firm-specific challenges, industry-wide trends, and regulatory impacts on product commercialization. To systematically assess R&D facilities and commercialization endeavors within the examined organizations, investigators developed and implemented observational protocols. The collected data were supplemented with information from public and government databases. Data collection tools were thoroughly examined for completeness and consistency to ensure the accuracy of the collected data.

### ***Data analysis***

The data were then entered into Microsoft Excel, organized, and meticulously cleaned before analysis using the Statistical Package for Social Scientists (SPSS) 26.0. Statistical trends were extracted from the survey data through quantitative analysis, while interview responses underwent coding and thematic examination to elucidate common CVD determinants. The results from both methodologies were subsequently cross-referenced to derive comprehensive conclusions regarding the factors that influence CVD in Uganda. To gain further insight into the commercialization processes within firms, an explanation-building procedure was employed in the cross-case analysis (Plotz, 2020). The synthesized data were then organized into chronologically arranged matrices that were used to draw conclusions.

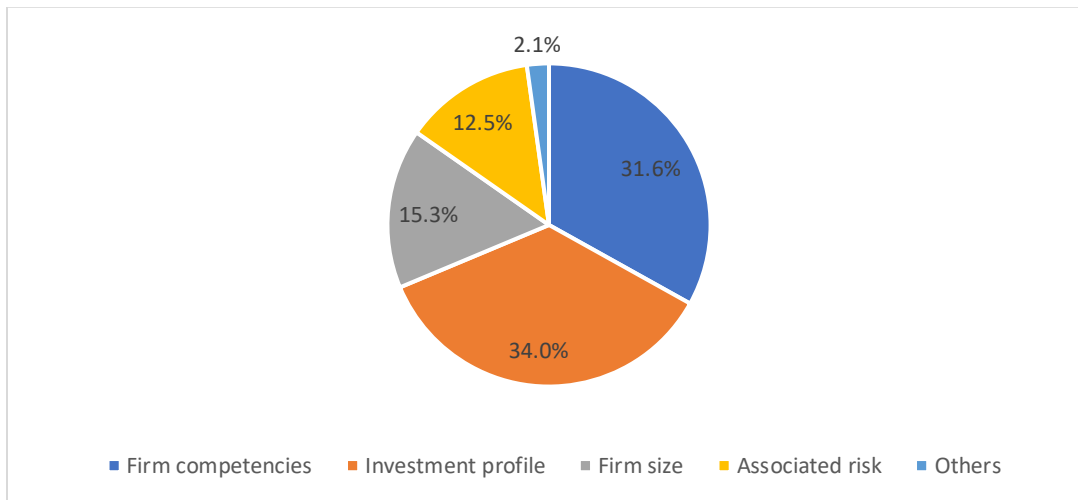
## **Results and Discussion**

### ***Firm-specific determinants of commercialization valley of death***

The firm-specific determinants play a pivotal role in the commercialization of innovations, as they directly impact a firm's ability to introduce new products, services, or technologies to the market.

#### ***Firms' competencies, knowledge, and expertise***

A firm's success depends on its ability, knowledge, and expertise (Atiase et al., 2020; Kesselring et al., 2023). In a survey, 36.1% of the Ugandan firms identified these factors as crucial for commercializing technological innovation (Figure III). According to research, a product with advanced technology may not always perform better than a product with less technology, but effective management and marketing. Uganda has a long history of business practices and is known for its uniquely crafted products (Fashina et al., 2018; World Bank, 2021). Our findings suggest that individuals with strong technical skills and experience in Uganda's knowledge-based economy oversee startups and techno-business firms in the country.



**Figure III: Firm-specific determinants of CVD**

Management and marketing expertise is often overlooked in favor of technical professionals, who prioritize technological advancements over effective communication with target clients. Several studies have found a deficiency in non-technical skills, particularly in fields such as technical product sales and marketing, which hinders the commercialization process in Ugandan enterprises. Firms that employ personnel with diverse backgrounds and expertise are better equipped to address this challenge and develop successful solutions to genuine problems.

#### *Investment-related issues and value proposition*

A unique value proposition is crucial to a product's success, as noted by Abbas et al. (2018) and Zhu et al. (2020). This proposition can take the form of enhanced efficiency, productivity, or performance, thereby providing users with additional advantages. According to this study, 34% of firms identified investment-related challenges and value propositions as firm-specific factors affecting the commercialization of innovations in Uganda (Figure III). Although technology has the potential to solve problems and generate positive economic impact, it is unlikely to succeed financially if people are unwilling to pay. Furthermore, such technologies struggle to gain the trust and support of investors seeking reasonable returns on their investment. Many products in Uganda have failed to gain market share because of entrepreneurs' poor management of business obstacles (World Bank, 2021). This issue is exacerbated when firms do not consider customer feedback during their product development.

#### *Firm size and collaborative nature*

Firms must strive for optimal harmony between their assets and capabilities to thrive in an uncertain and resource-intensive environment, as suggested by Abbas et al. (2019) and Atwine et al. (2023). According to a survey, 15.3% of the studied firms identified company size and collaborative nature as key factors affecting technological innovation commercialization in Uganda (Figure III). Collaboration enables firms to share resources and information, and access new markets and technology, leading to cost savings, increased sales, and improved product value.

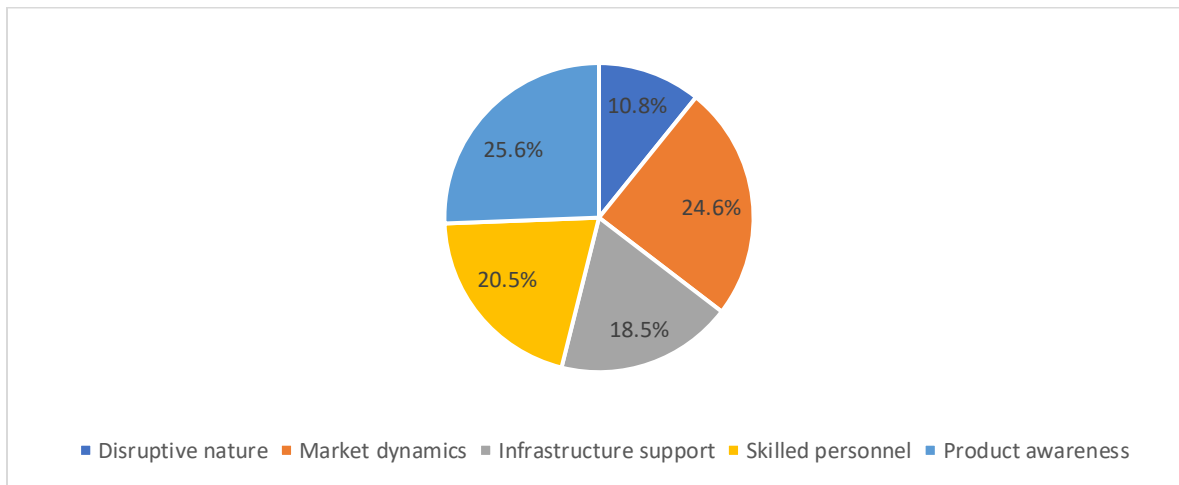
Collaboration with organizations in related fields can help techno-business firms avoid direct competition and benefit from their shared expertise. This approach can expedite expansion, reduce costs, and compensate for a lack of internationalization experience by providing the necessary information and support. As Abbas et al. (2019) and Atwine et al. (2023) indicate, establishing a strong international presence typically requires collaboration, which helps firms to overcome international expansion challenges.

*Nature of risk within a firm*

The success of entrepreneurship and venture development is not solely dependent on financial elements, market dynamics, and legal frameworks but also on the cultural and psychological characteristics of individuals within society and a firm (Kim et al., 2019; Saka-Helmhout et al., 2020). As indicated by the study, 12.5% of firms in Uganda identified the nature of risk within a firm as a firm-specific factor influencing the commercialization of innovations (Figure III). Firms that are willing to take risks and explore new territories are more likely to succeed in their current or future markets. A firm’s ability to take risks is influenced by various factors, including experience, behavior, personal mentality, social influences, and the overall environment. However, some firms have slow growth and have no plans for expansion.

*Market-centric determinants of commercialization valley of death*

The influence of market-centric determinants on the commercialization of inventions is substantial, as they pertain to comprehending and gratifying the demands and preferences of the target market. They are vital for guaranteeing that innovation has a viable market and that it fulfills customer needs effectively.



**Figure IV: Market-centric determinants of CVD**

*Level of public awareness and product acceptance*

The need for technological advancement in Uganda is primarily driven by social issues, as indicated by Fashina et al. (2018) and Atwine et al.(2023). According to the survey, 25.6% of firms view public awareness and product acceptability as crucial market-driven factors affecting



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innovation commercialization in Uganda (Figure IV). Addressing the high cost of adoption is essential for overcoming this barrier to innovation development and adoption.

Several researchers have argued that a product's value in the eyes of customers determines its price (Crowley & McCann, 2018; Kim et al., 2019; Avenyo et al., 2021). To justify the higher prices of advanced technology, it is essential to emphasize its benefits, which outweigh the increased costs to users. Ugandan society's focus on enhancing social conditions and well-being makes it crucial to raise public awareness and embrace innovation for successful commercialization.

### *Market dynamics and size*

Uganda's technological innovation market growth is influenced by global demand for modern technology and social transformation. Advanced technology, technical talent, and support infrastructure are opportunities in Uganda. The survey found that 24.6% of the firms identified market dynamics and size as market-centric factors. However, Uganda's limited domestic market and lack of widespread technological breakthroughs pose challenges.

According to Fashina et al. (2018) and the World Bank (2021), the commercialization of technology in Uganda requires adjustments to infrastructure and consumer behavior. Therefore, deliberate effort is required to meet this demand. Domestic procedures and legislation can promote and facilitate the use of new technology and firms can receive assistance when entering foreign markets. Techno-business firms with substantial market knowledge, technological expertise, and a forward-thinking mindset dominate the Ugandan sector (NPA, 2020; World Bank, 2021). However, these firms often face financial constraints and lack knowledge of global expansion, limiting their potential in domestic markets with limited potential.

### *Availability of skilled personnel and innovation clusters*

Collaboration among techno-business firms, government agencies, and research institutions is crucial for commercializing innovation in Uganda (Abbas et al., 2019; Zhu et al., 2020). Of the firms surveyed, 20.5% identified skilled personnel and innovation clusters as market-driven factors influencing commercialization (Figure IV). To promote firm growth and encourage local inventions, the government should actively embrace new technologies and leverage the limited local markets.

This approach functions as a platform for real-time product showcasing and advertising to clients and stakeholders as well as a testing and refinement tool. Government support for industrial collaboration and international partnerships can further enhance these efforts. The Uganda Cluster Program has demonstrated significant success in promoting technology integration and utilization in the domestic market (Ecuru et al., 2014; Mulumba et al., 2017).

### *The existence of incubation facilities and infrastructure support*

Techno-business firms require access to incubation facilities and infrastructure support, as reported by researchers (Kwesiga, 2019; Zhu et al., 2020). Of the firms surveyed, 18.5% identified these factors as critical for commercializing innovation (Figure IV). Incubators, accelerator programs,



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research groups, and facility parks can provide various types of assistance (Abbas et al., 2018; Kwesiga, 2019). Opportunity exists in offering cost-cutting, expert-driven solutions in countries such as Uganda, which is known for its innovative culture and its technical universities. As bio-based firms grow, there is a need for network support.

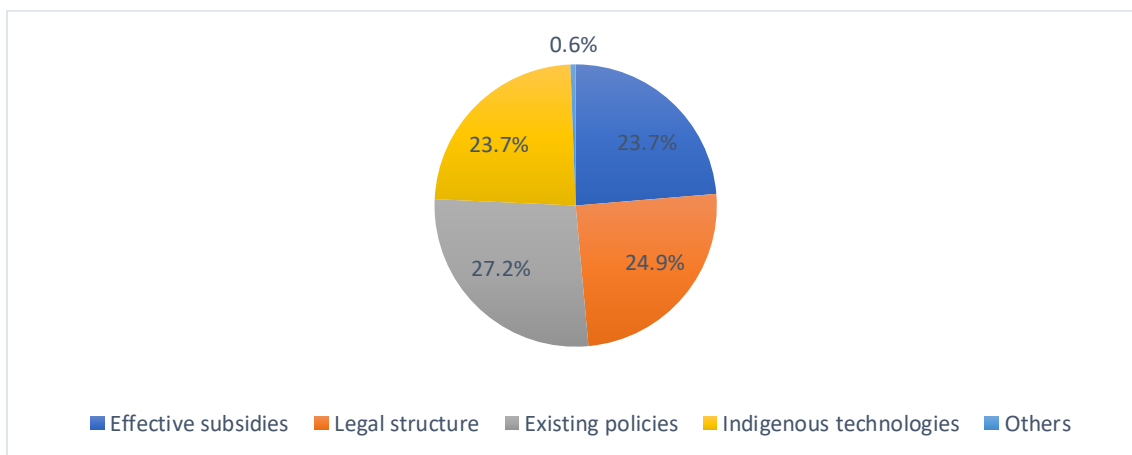
### *Disruptive nature of the industry*

Industry disruptions caused by technological advancements, shifting customer preferences, or innovative strategies can present challenges and opportunities for businesses attempting to introduce innovation. In Uganda, 10.8% of firms cited industry disruption as a market-driven factor impacting the commercialization of technological breakthroughs (Figure IV). Firms that disrupt the market often attract many participants, leading to heightened competition from both new market entrants and established competitors who continuously introduce innovative products or services. This increased competition poses a challenge for firms to differentiate between themselves and achieve market dominance (Crowley & McCann, 2018; Rajapathirana & Hui, 2018). To succeed in this environment, businesses must possess greater distinction, scalability, and marketing acumen, which may also elevate barriers to the entry of new ideas.

Rapid technological advancements often disrupt the market, rendering new products or services obsolete. According to Atwine et al. (2023), firms must continuously enhance their offerings to remain competitive. Failure to adapt may result in a loss of market share or obsolescence of firms. In this fast-paced market, firms must be able to quickly identify emerging trends and seize new opportunities to gain a competitive edge. Market disruptions can lead firms to redirect their focus and incorporate innovative business strategies for the successful commercialization of disruptive technologies, which are vital for sustainable growth.

### *Policy-related determinants of commercialization valley of death*

Policy-related determinants significantly affect the commercialization of inventions. These factors affect the regulatory and business environments in which firms operate and can either speed up or slow down the process of bringing ideas to the market.



**Figure V: Policy-related determinants of CVD**



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### *Consistent innovation and commercialization policy environment*

A well-balanced regulatory framework and government assistance programs are essential for promoting innovation adoption (UNCTAD, 2020; Aktar et al., 2021). In Uganda, 27.2% of the firms identified a stable innovation and commercialization policy environment as a key factor affecting innovation commercialization (Figure V). Although Uganda has made notable progress in becoming a significant market player through effective policies and processes that foster growth, concerns have been raised regarding the lack of a comprehensive and consistent policy approach. Appropriate policies implemented by the government are crucial for creating favorable conditions that drive technological advancement (Uyarra et al., 2020; Aktar et al., 2021).

### *Prevailing legal structure*

According to the Global Entrepreneurial Monitor (GEM), Uganda has a favorable legislative environment that supports entrepreneurial activity (GEM, 2022). It outperforms other countries in providing government support for entrepreneurial initiatives, business creation, and development. However, 24.9% of the surveyed firms identified the current legislative structure as a policy-related issue hindering the commercialization of innovations in Uganda. Although the regulatory environment is generally stable and supportive of firms, there is room for improvement in the technological licensing process, which is complex and involves numerous procedures and standards (Fosci et al., 2019; CHANE & Atwal, 2023). Enhancing Uganda's legal framework would enable firms to accelerate the commercialization of technological innovation.

### *Effectiveness of subsidies and support schemes*

Techno-business firms in Uganda's technology sector lack resources, and small firms require additional funding to transform their concepts into significant innovations. Subsidies and support schemes were cited by 23.7% of the firms surveyed as policy-related factors affecting the commercialization of technological advancements in Uganda, aligning with the perspectives of numerous researchers who emphasize finance's significance for businesses as a crucial factor for their continued operation.

Although Uganda's GERD is low compared with similar economies, financial support for techno-business firms is essential. Although some firms receive assistance from organizations such as the Uganda Development Bank (UDB), obtaining funding, especially from later-stage firms, remains a significant challenge. Studies by Kim et al. (2019) and Zhu et al. (2020) emphasize the importance of adequate funding at all stages, including R&D and the intermediate phase, before the market launch. Improving the lengthy process of providing financial assistance through centralized start-up support and single-allocation disbursements can address this challenge.

### *Inadequate use of indigenous technologies*

This study analyzed the role of indigenous technology in promoting sustainable economic growth, preserving cultural diversity, and improving the livelihoods of local communities. It was found that 23.7% of the firms surveyed identified a lack of utilization of indigenous technology as a policy-related issue hindering innovation commercialization in Uganda. Indigenous technologies can play a significant role in commercializing inventions and contributing to economic growth,



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social progress, and cultural preservation (Ongâ & Abbey, 2019; NPA, 2020). Uganda's rich cultural diversity and traditional knowledge systems provide a promising platform for the commercialization of indigenous innovations.

Traditional farming methods such as agroforestry, crop rotation, and organic farming offer sustainable alternatives to conventional techniques that benefit the environment. Additionally, commercializing indigenous medical knowledge can preserve traditional therapeutic practices and provide economic opportunities according to Ongâ and Abbey (2019). Similarly, commercializing indigenous creative traditions can help craftsmen support themselves, boost cultural tourism, and preserve cultural heritage.

### **Conclusion, Future Research and Recommendations**

#### ***Conclusion***

The government and policymakers must ensure the effective enforcement of policies to overcome CVD and enhance the commercialization of generated innovations in Uganda. The findings reveal gaps and obstacles within the innovation ecosystem and industry, leading to recommendations for actions and interventions to address them. To bridge the existing gaps in the innovation ecosystem and industry, policymakers must take critical steps such as increasing support for innovation in the research system and industry. Uganda has made notable advancements in fostering a beneficial environment for innovation and commercialization. However, some areas require further enhancement. Although there are various prospects for research and commercialization, there is currently no dependable funding mechanism for long-term projects in the fields of science, technology, and innovation (STI) because of the government's shifting priorities and the absence of a well-defined national research and commercialization agenda.

#### ***Ideas for future research***

While this research has identified key factors influencing CVD in techno-business firms, it also highlights a significant gap in our understanding of how firm-specific elements such as operational strategies and marketing proficiency contribute to narrowing CVD. Subsequent investigations should explore the specific mechanisms by which these factors impact firms, potentially comparing successful firms with those that have encountered challenges in this domain. Further research is necessary to examine the long-term effects of alternative funding methods on the viability of Ugandan techno-business enterprises. Moreover, scholars can assess the efficacy of online marketing approaches for enhancing product recognition and adoption across diverse consumer segments.

One area that necessitates further investigation is the collaborative interactions within innovation ecosystems. Subsequent studies should examine methodologies to enhance partnerships and networks among academic institutions, technology-focused enterprises, governmental entities, and private investors to foster an environment conducive to the commercialization of innovations. This study underscores the need to modify current policies to establish a more favorable ecosystem to bring innovations to the market. Future investigations should assess the efficacy of existing



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subsidies and support programs with the objective of proposing policy amendments that more effectively address the needs of technology-oriented firms confronting CVD. While this study emphasizes the significance of managerial and marketing proficiency in surmounting CVD, it also reveals a dearth of knowledge regarding the most effective marketing approaches in the context of Ugandan techno-business firms. Further research could investigate the comparative impact of digital and conventional marketing methodologies on the successful commercialization rates of these enterprises.

### ***Recommendations***

#### *Exploring alternative funding sources*

Firms should explore alternative funding sources such as venture capital, investors, government subsidies, and crowdsourcing. Given the increasing adoption of mobile technology in Uganda, techno-business enterprises should consider utilizing crowdfunding platforms that are accessible via mobile devices to secure alternative financing. This strategy could prove particularly advantageous in attracting support from Ugandan expatriates who may be inclined to invest in innovative projects within their country of origin. Adequate capital allows firms to invest in R&D, scale up manufacturing, effectively market, and disseminate innovation. One of the major challenges in commercializing breakthroughs is the risk of IP infringement, which requires firms to prioritize IP protection through patents, trademarks, copyrights, and trade secrets. Strong IP protection provides legal protection and enhances a firm's ability to profit from its inventions.

#### *Enhancing product awareness*

Product awareness improves uptake, commercialization, and use among the public. To achieve this, firms must emphasize their benefits, characteristics, and distinctions when using digital marketing channels and social media platforms to reach a broader audience. Thus, enhancing product recognition requires a comprehensive strategy. Digital marketing methodologies, such as utilizing social media platforms and developing engaging content, function as efficacious means of augmenting brand exposure. Nonetheless, firms should prioritize superior product quality, customize marketing approaches, and cultivate affective connections with their target demographics to establish robust brand recognition. Through seamless integration of these elements, enterprises can effectively elevate their product visibility and secure a competitive advantage in the marketplace.

#### *Streamlining the technology licensing process*

To optimize the technology licensing process, a well-balanced strategy is essential to enhance both resource allocation effectiveness and decision-making efficiency. A streamlined licensing process reduces costs and bureaucracies, thereby facilitating benefit-sharing associated with accrued royalties. To address this, the government should establish clear, transparent regulations, and predictable approval processes. Additionally, regulatory agencies must be prepared to modify legislation as technology advances, to avoid stifling innovation.



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### *Promoting customer-oriented product development*

Global market dynamics Uganda's domestic market, generating both opportunities and challenges for techno-business enterprises. A comprehensive analysis of how consumer preferences worldwide influence local demand can yield crucial insights for companies seeking to adapt their offerings to international markets. To ensure customer-centric development, firms should conduct market research, establish channels for obtaining consumer feedback, and engage with potential customers during product development. By aligning their products with client needs, firms can improve their prospects for commercialization.

### *Developing incubation support facilities*

The establishment of incubation centers that prioritize industries in which Uganda possesses a competitive advantage, such as agricultural technology and sustainable energy, could provide specialized assistance for innovation, demonstrating the greatest potential for commercial viability and positive social impact. These facilities support product iteration and refinement, allowing businesses to make the necessary adjustments before expanding. To ensure that innovations meet the expanding market needs without compromising quality or performance, businesses must design innovations with scalability.

### *Developing effective funding guidelines and support mechanisms*

This study underscores the critical significance of supportive governmental policies, culminating in a specific recommendation for policymakers to establish specialized techno-business innovation funds. Such a fund could directly address the challenges pertaining to investment and value propositions by providing initial capital, financial incentives, and guidance programs for nascent enterprises during the crucial early stages of product development. These programs can further provide grants, tax incentives, low-interest loans, and investments in startups to support innovation-driven businesses financially.

### *Encouraging partnerships and collaborations*

Collaboration enables access to production, distribution, and marketing expertise. The implementation of the innovation cluster model could potentially accelerate the commercialization of innovations in Uganda's key economic sectors. This approach facilitates collaboration between businesses, educational institutions, and governmental entities in the development of techno-business initiatives. Enhancing marketing capabilities for innovative products by combining the specialized knowledge of multiple businesses is another benefit. Licensing agreements can alleviate constraints related to manufacturing, distribution, or market access, as firms can use established distribution channels and partners' proven market presence.

### *Engaging the private sector*

Firms can consider various funding options such as venture capitalists, angel investors, government grants, and crowdfunding platforms. A strong financial position enables firms to implement scaling, marketing, and market-entry strategies. The availability of private investments can be critical in helping firms overcome market-centric challenges and successfully commercialize their innovations. To enhance private sector investment in innovation, Uganda may



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consider implementing tax incentives for R&D initiatives and technology-oriented start-up enterprises.

### *Investing in education and skill development programs*

Sustainable economic growth and global competitiveness depend heavily on investment in education and skills training. This investment enhances individual earnings and productivity and promotes societal advancement. Given increasing life expectancy, it is imperative to retrain and update workers' skills, necessitating a fundamental shift in the approach to education and skill development throughout an individual's lifespan. To facilitate long-term economic progress and address the challenges posed by rapid technological advancements, policymakers must prioritize consistent investment in education. Education and skill development also enhances product development, technology transfer, and diffusion among the masses.

### *Limitations of the study*

Focusing on Uganda, this study provides an in-depth examination of a specific context, albeit limiting the generalizability of our findings. Multi-country comparative analyses could elucidate whether the identified CVD factors are globally applicable or specific to Uganda's socioeconomic milieu. Although our quantitative methodology yielded valuable insights into CVD determinants, it constrained our capacity to explore individual experiences. This study presents a contemporary overview of the determinants of CVD in Uganda. However, given the rapid progression of technological advancements and market dynamics, longitudinal studies are essential for monitoring these factors and their effects over time.

### **Declarations**

**Data availability statement:** The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

**Disclosure statement:** The authors declare no conflict of interest.

**Author contributions:** All authors contributed to the writing of the manuscript and read and approved the final manuscript.

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# CERTIFICATE OF PARTICIPATION

6<sup>th</sup> AfricaLics Research Conference at University of Ilorin, Nigeria  
13<sup>th</sup> – 15<sup>th</sup> November 2024

**« The Africa We Want: Leveraging Innovation and Digital Transformation »**

Vice Chancellor - University of Ilorin and the President of the AfricaLics Network  
Attest that

**Ronald Jjagwe**

Co-authored a paper presented at the conference titled “Firm-specific, market-centric and policy-related determinants of ‘commercialization valley of death’ encountered by techno-business firms in Uganda”

Vice Chancellor  
University of Ilorin  
**Prof. Wahab Olasupo Egbewole SAN**

President  
AfricaLics Network  
**Prof. Daniel Kitaw**

**Determinants of the Commercialization ‘Valley Of Death’ among Ugandan Researchers, Innovators, and Techno-Business Firms**



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**Purpose:** Firms typically invest a significant portion of their resources into basic research to produce new ideas and technologies. However, turning them into marketable products is challenging. Firms often struggle to bridge the gap between prototype development and successful product commercialisation. Scholarly literature provides little guidance on how this gap can be overcome and what role broader organizational factors play in this process. The main objective of this study was to assess the determinants of CVD among researchers, innovators, and techno-business firms in Uganda.

**Design/methodology/approach:** A qualitative research method was employed, using interview and observation approaches. This method involved gathering various types of evidence, including documents, observations, artefacts and interviews with selected individuals in the field. Systematic observation was conducted to understand interaction(s) and contextual factors associated with CVD. Interviews were conducted to gain insights and experiences on the determinants of CVD. The collected data was supplemented with information from government R&D databases.

**Findings:** The study findings indicated that market dynamics, strong R&D infrastructure, technological expertise, product awareness, and supportive government regulations are crucial determinants of CVD among researchers, innovators, and techno-business firms. To overcome CVD, the study proposes developing financial systems, encouraging partnerships/collaborations, facilitating globalization, and establishing R&D infrastructure.

**Originality:** This study makes theoretical and policy contributions by highlighting the determinants of CVD. The study also proposes an intervention framework at the policy, firm, and market levels. Ultimately, this study presents a solution that can be implemented by firms to improve the benefits of innovative technology and product development for commercial gain and overall economic growth.

**Implication:** Bridging CVD hinges on sustainable financial systems, effective partnerships/collaborations, strong global linkages, and availability of R&D infrastructure. This will generate transformational development by increasing industrial output and strengthening linkages between researchers, innovators, and the private sector.

**Keywords:** commercialization valley of death, innovators, researchers, techno-business firms, Uganda.

## **PAPER VI**

## **Nurturing technopreneurship: bridging the commercialization valley of death among Ugandan researchers, innovators, and techno-business firms**

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### **Abstract**

Despite Uganda's rich potential for innovation and technopreneurship, the transition from prototype development to marketable products remains a significant challenge that contributes to the broader commercialization valley of death (CVD). The current literature offers limited insight into effective strategies for navigating CVD in developing countries, particularly in relation to organizational factors and the unique market dynamics of Uganda. This study aims to bridge these knowledge gaps by evaluating the determinants of CVD among Ugandan researchers, innovators, and techno-business actors using a mixed-methods approach. Utilizing a combination of interviews and systematic observations, this study selected 116 participants through purposive sampling to gain deep insights into the multifaceted determinants of CVD, aligning with the goal of understanding both the qualitative and quantitative aspects of commercialization challenges in Uganda. The inclusion criteria were based on the participants' research and development (R&D) expertise and their involvement in the commercialization process. The collected data were supplemented with information from government R&D databases. The findings reveal that market dynamics, robust R&D infrastructure, and supportive government regulations are among the crucial determinants of CVD, offering new perspectives for bridging CVD in Uganda. This study proposes a comprehensive framework that integrates policy-, firm-, and market-level interventions to bridge the CVD. For instance, a techno-business startups must navigate market dynamics, leverage R&D infrastructure, demonstrate technological expertise, raise product awareness, and comply with governmental regulations. By highlighting these determinants, this study provides valuable theoretical and policy insights that can guide the development of targeted interventions to foster technopreneurship and innovation commercialization in Uganda.

**Keywords:** Commercialization, Commercialization valley of death, Innovation, Research and development, Techno-business firms, Technopreneurship, Uganda

## **Introduction**

The commercialization valley of death (CVD) signifies the gap between developing new scientific knowledge and commercializing new products (Huizingh & Biemans, 2020; Ellwood et al., 2022; Takata et al., 2022). Many firms struggle to transform scientific research into marketable products, and the shift from invention to innovation is a major hurdle. Industry estimates indicate that four out of the five new inventions have never reached the market (Gbadegeshin et al., 2022; Zhang et al., 2023). This is troubling because inventions often present significant opportunities to launch radically new products. Firms invest heavily in developing new technologies, but these investments cannot be considered if the technologies are not commercialized. The CVD concept is typically viewed as the divide between scientists' basic research and firms' product development (Takata et al., 2022; Helman, 2023).

Despite extensive documentation, the scholarly literature provides limited guidance on bridging this gap among researchers, innovators, and techno-business actors. Most empirical studies on CVD in developing countries neglect the entrepreneurial intentions of researchers, innovators, and techno-business actors (Al-Shaikh & Siddiqui, 2021; Lefebvre et al., 2022). Previous research has explored the roles of governments, public institutions, and venture capital firms in fostering innovation and addressing the funding gap related to CVD (Lefebvre et al., 2022; Roca & O'Sullivan, 2022). However, studies on CVD within the same firm, rather than in other organizations such as research institutions and techno-business enterprises, have been scarce. These studies have primarily focused on individual roles in promoting new product development. Insufficient attention to firm-specific factors that may influence the crossing of CVD is a notable gap in existing research, which this study aims to fill.

The national innovation ecosystem in developing countries, such as Uganda, lacks effective linkages between various actors and has insufficient connections between knowledge creators and users (Guimón, 2013; Mulumba et al., 2017). To foster technopreneurship and bridge CVD in Uganda, it is essential to coordinate STI policies among stakeholders, monitor and learn from existing support activities, and draw lessons from entrepreneurial experiences (Al-Shaikh & Siddiqui, 2021; Ellwood et al., 2022). Firm-specific factors can act as critical links between innovative ideas and their successful implementation, akin to building a pathway across

challenging terrains, requiring careful coordination and understanding of the organizational landscape to effectively navigate the valley of death in commercial ventures.

Developing comprehensive models for high-tech startups and implementing incubation programs can help overcome CVD (Kwesiga, 2019; Gbadegeshin et al., 2022). For example, a Ugandan startup creating a mobile app for precision agriculture may struggle to connect with local agricultural research institutions, limiting access to essential crop data and expertise. This gap can be bridged by establishing a national platform for collaboration between technology entrepreneurs and agricultural scientists, leading to more effective and locally relevant agri-technological solutions (Pius & Owin, 2024). Success depends on collaboration among universities, government agencies, and the private sector to foster an innovation-friendly environment (Loganathan & Subrahmanya, 2022). To understand the complexities of CVD, researchers, innovators, and techno-business actors must not only generate useful knowledge and ideas, but also collaborate to promote prototype commercialization, inspire marketable product design, and lead successful commercialization efforts.

Despite Uganda's rapid growth in research and technological innovation, there remains a significant gap in understanding how local socio-economic factors, such as limited access to venture capital and insufficient regulatory frameworks, exacerbate CVD for Ugandan technopreneurs. In Uganda, this gap is evident in the renewable energy technologies developed by researchers, which often face challenges in market applications owing to scalability or economic constraints (Twaha et al., 2016; Fashina et al., 2018). Previous studies have primarily focused on the technological and financial aspects of CVD, with scant attention paid to the role of organizational culture, market readiness, and the policy environment in Uganda's context. This study sought to fill this gap by examining how these factors contribute to the persistence of CVD among Ugandan technopreneurs.

This study contributes to the literature by offering a comprehensive framework that not only identifies the determinants of CVD in Uganda, but also integrates policy-, firm-, and market-level interventions. Such a multifaceted approach has scarcely been addressed in existing studies, particularly within the context of developing economies such as Uganda. Investigating CVD in Uganda is crucial because of the burgeoning technology industry and the government's increasing investment in research and development. Understanding the barriers to commercialization in this

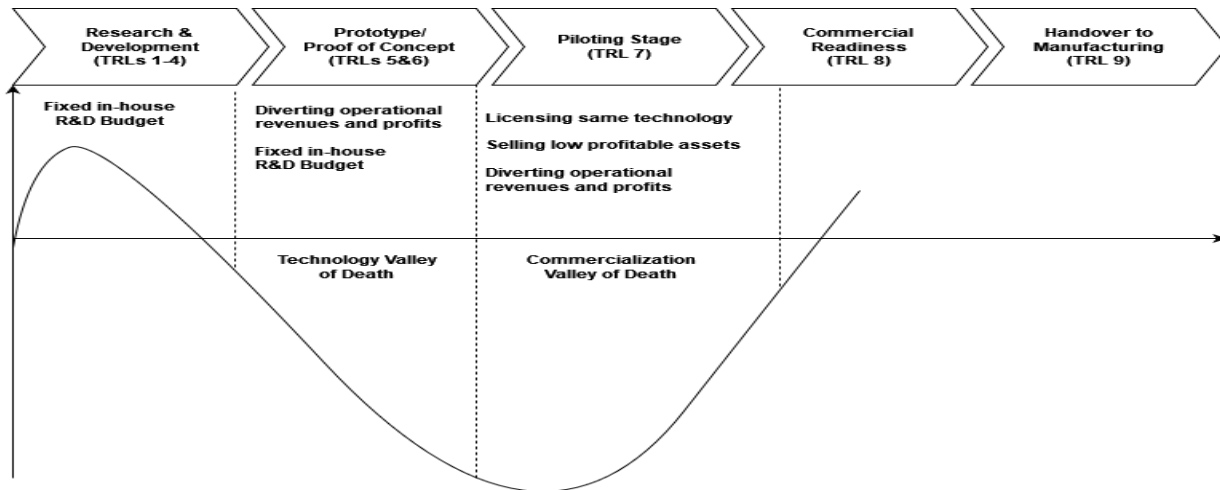
context can provide valuable lessons for other emerging economies facing similar challenges. Utilizing a mixed-methods approach that combines qualitative and quantitative data from a wide range of stakeholders, this study offers a more nuanced understanding of the multifaceted nature of CVD in Uganda, which previous studies have not explored comprehensively.

However, the proposed framework might not address all commercialization challenges in Uganda, and focusing solely on researchers, innovators, and techno-business actors may neglect other crucial stakeholders in the innovation ecosystem. Additionally, the study's emphasis on commercial gain and economic growth could overlook the essential social and environmental considerations necessary for sustainable development in Uganda. A multifaceted approach is necessary to effectively bridge CVD, including the effective management of innovation through technology transfer offices (TTOs) (Suryati et al., 2020), providing technopreneurship education in universities (Hardi et al., 2022), and developing business models that facilitate the commercialization of new technologies (Wang & Chebo, 2021). Furthermore, creating an ecosystem that supports the commercialization of innovations can help nurture technopreneurship. Thus, a collaborative effort between educational institutions, industry, and policymakers is crucial to successfully transition from research to market, and to support the growth of techno-business firms (Zhuang et al., 2021; Noya & Taneo, 2023).

## **Literature review**

### ***The concept of commercialization valley of death***

Commercialization valley of death (CVD) occurs during early science-based innovation, when a technology's advancement is hindered by insufficient funding and support. This phase lies between technical invention and commercialization readiness efforts (Ellwood et al., 2022; Huizingh & Biemans, 2020). This is marked by an inability to move from technology demonstration to commercialization (Figure I). This phase occurs at a critical juncture in technological development when scientific research activity has not yet been completed, and the commercialization of this technology is not yet fully understood.



**Figure I:** Technology and commercialization valley of death (Upadhyayula et al., 2018)

Technology transfer across CVD presents significant management challenges (Dean et al., 2022; Son et al., 2022). The early stages of science-based innovation are marked by uncertainty in technology and market understanding, leading to investment decisions based on an insecure foundation. This phase's organizational complexity is contrasted by the more structured innovation functions of research and commercialization. These functions operate under distinct institutional logics, as research and commercialization have different normative and cultural frameworks. Managing the transition between the valley of death is essential for preventing barriers to technological knowledge transfer (Al-Shaikh & Siddiqui, 2021; Takata et al., 2022). For instance, differences in intellectual-property-related cultural and normative logic can cause conflicts in invention disclosure, patent licensing, and ongoing IP use in research.

Commercialization valley of death is challenging due to funding gaps, market demands, and policy obstacles (Al-Shaikh & Siddiqui, 2021; Ellwood et al., 2022). Transitioning between the research and commercialization phases often requires the management of organizational culture and communication to bridge scientific and business perspectives. Successful navigation involves clear technology transfer protocols, fostering interdisciplinary collaboration and creating incentives that align research with commercial goals. This would require adopting a multifaceted strategy, including intermediaries, policy reforms, and support structures such as accelerators (Al-Shaikh & Siddiqui, 2021; Ellwood et al., 2022). This phase is critical, as many promising technologies fail to reach the market, highlighting the need for focused support and innovation management (Ellwood et al., 2022).

Techno-business firms may benefit from specialized teams dedicated to transferring knowledge and technologies across institutional boundaries. However, some argue that excessive intervention can distort markets and inefficiently allocate resources. Critics believe that natural market forces should determine technology success, ensuring that only viable innovations reach commercialization (Demirel & Kesidou, 2019). They also caution that over-reliance on support structures might create false demand for technologies that lack genuine market potential.

### ***Effect of CVD on innovation commercialization***

The commercialization of basic scientific research is a key area of study in modern innovation, significantly impacting national innovation ecosystems. Research has examined the commercialization process via spin-out enterprises, identifying critical junctures, such as the transition from the research phase to the opportunity-framing phase, where complex issues must be resolved for science-based innovations (Budi & Aldianto, 2020; Huizingh & Biemans, 2020). While these studies highlight the need to blend scientific knowledge with market understanding, they lack details on how this transition occurs.

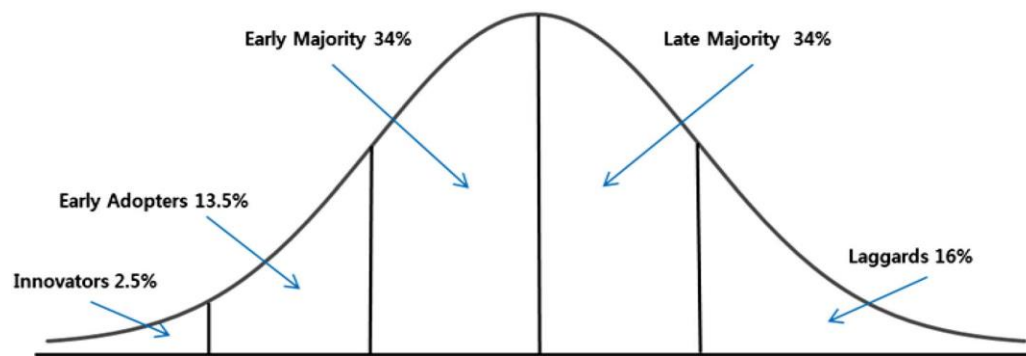
Researchers have acknowledged the absence of a comprehensive framework to explain the emergence of CVD and the related spin-out processes (Ellwood et al., 2022; Ojubanire et al., 2023). They emphasize that robust technological research and extensive knowledge accumulation are critical factors. However, a detailed analysis has yet to reveal how research knowledge transforms into a form that initiates commercialization efforts (Ellwood et al., 2022; Son et al., 2022). CVD is often linked to underinvestment in R&D, but Helman (2023) argues that non-economic investments, such as government funding for early-stage research, play a role without considering subsequent investment decisions. Additionally, Helman (2023) points out the lack of targeted stimuli for the post-R&D and pre-market stages, indicating that current incentives do not fully support the innovation lifecycle.

Commercialization valley of death significantly hampers technological commercialization due to funding complexities, strategic partnerships, and market conditions (Helman, 2023; Kesselring et al., 2023). While these studies highlight CVD's causes and solutions, they may neglect the role of market demand and consumer preferences in driving innovation. Critics argue that some commercialization failures stem from insufficient market needs or consumer interests, not just

funding gaps or weak partnerships (Butnik-Siverskyi et al., 2024). Furthermore, focusing on government funding and public-private collaborations might underestimate market-driven solutions and private sector initiatives' potential to bridge the commercialization gap.

### ***Technology adoption lifecycle and innovation commercialization***

The technology adoption lifecycle (TAL) outlines the acceptance of new products based on the demographic and psychological traits of adopter groups. The S-curve represents products that incorporate new technologies and market trends (Byun et al., 2018; Mogull, 2021). The lifecycle curve is illustrated by plotting the time on the horizontal axis and the cumulative number of adopters on the vertical axis (Figure II).



**Figure II:** *Technology Adoption Lifecycle* (Byun et al., 2018)

Byun et al. (2018) note that innovators, who first embrace discontinuous innovation, make up about 2.5% of all consumers. Early adopters accounted for approximately 13.5% of the total. The early majority, or pragmatists, who adopt slightly ahead of the general population, comprise approximately 34% of the population. The late majority, or conservatives, accounted for 34%. Lastly, laggards or skeptics, who are very cautious about innovation, constitute approximately 16%. This adoption cycle indicates that technological innovations do not immediately impact the market and consumers as they require time to promote the adoption of products, technologies, or ideas associated with uncertainty and risk (Byun et al., 2018; Mogull, 2021).

While the TAL model is well established, its application varies by context. Mogull (2021) noted the need for distinct marketing strategies throughout the lifecycle, particularly for technical products, which necessitates an understanding of consumers' psychological motivations. (Chen, 2024) provides empirical support for this model in secondary education, highlighting the importance of early adopters and interpersonal networks in spreading new teaching methods. This

implies that although the lifecycle model is broadly applicable, the factors influencing adoption can differ significantly based on specific innovation (Mogull, 2021; Chen, 2024).

TAL provides a framework for understanding the spread of innovation within a social system, but the adoption factors can vary. Marketing strategies, individual and organizational traits, and perceived innovation attributes influence adoption in different contexts. Although the stages of the model are consistent, the dynamics within each stage are complex (Mogull, 2021; Chen, 2024). TAL may oversimplify the non-linear nature of innovation diffusion. Critics argue that it overlooks potential reverse adoption or discontinuance at any stage, and that its categorization of adopters into distinct groups fails to capture the nuanced decision-making processes in today's fast-evolving technological landscape.

### ***Summary of key points from the literature review***

However, the specific mechanisms through which government policies and support systems influence the commercialization process in the context of Uganda's unique socio-economic environment remain underexplored. Similarly, while firm-specific factors such as organizational culture and technology transfer practices are known to impact commercialization success, their specific manifestations and impacts within Ugandan techno-business firms have not been detailed.

While studies such as Helman (2023) and Kesselring et al. (2023) have highlighted the role of market demand and strategic partnerships in overcoming CVD in developed countries, there is a gap in understanding how these factors play out in the Ugandan context, where market dynamics and innovation ecosystems may differ significantly. The existing literature lacks a comprehensive theoretical framework that integrates market dynamics, government policies, and firm-level strategies in developing countries such as Uganda. This study proposes using a specific theory or model as a lens to examine the determinants of CVD among Ugandan techno-business firms, addressing a critical gap in the current literature.

## **Method**

### ***Study design and approach***

Given the exploratory nature of our study on the determinants of CVD in Uganda, we employed a mixed methods approach. Interviews allowed for an in-depth understanding and insights into the

personal experiences and opinions of the stakeholders involved, while systematic observations provided objective data on techno-business activities and dynamics. This combination was chosen to ensure both the depth and breadth of data necessary for a comprehensive analysis of CVD determinants. These methods highlight the need for a more dynamic and flexible approach to understand innovation adoption and technology. This involved incorporating feedback loops and iterative processes to capture the complexity of decision making in techno-business enterprises. A systematic procedure was followed to ensure trustworthiness, which was essential for the validity and reliability of the study, according to Plotz (2020).

### ***Study population***

Researchers, innovators, and techno-business actors were selected through purposive sampling based on the following inclusion criteria: a) involvement in at least one project aimed at bridging the CVD within the last five years; b) holding a position that directly influences R&D decisions, such as project managers, principal researchers, or executives of techno-business firms; and c) willingness to provide detailed insights into the commercialization processes, challenges, and strategies employed. These inclusion criteria for participant selection ensured that the study gathered insights from individuals with first-hand experiences in Uganda's innovation and technopreneurship landscape. The purposive sampling approach enabled researchers to target key stakeholders who could provide detailed information about the challenges and opportunities in commercializing innovations within the country's specific context. By focusing on participants with in-depth knowledge, this study aimed to uncover perspectives that might not be apparent by using broader sampling methods.

### ***Sampling method***

To ensure a representative sample of researchers, innovators, and techno-business actors in Uganda, we calculated the required sample size using a standard formula based on the expected proportion of innovative firms and a confidence level of 95%. Study participants were selected using purposive sampling to ensure a comprehensive understanding of the factors that influence CVD at the institutional level (Holliday, 2014; Manly, 2015).

The sample size was determined using the following formula:

$$n = \frac{Z^2 \times [P \times (1-P)]}{\alpha^2} \quad (\text{Manly, 2015})$$

Where;  $\alpha$  is the level of significance;  $e = 5\%$  [error];  $P = 0.917$  [% of entrepreneurs in Uganda (NPA, 2020; Sithole, 2020); and  $Z = 1.96$  [Z-value]

$$\text{Taking } \alpha = 5\%, \text{ Thus } n = \frac{1.96^2 \times 0.917 \times 0.083}{0.05^2} = 116$$

Therefore, a sample size of 116 participants was used in this study.

### ***Data collection***

The study was conducted in 2022, and the investigator administered the questionnaires to the participants. Online questionnaires were available to respondents who preferred to complete them on their own. A total of 71 responses were recorded from 116 participants, with a response rate of 61%. Semi-structured interviews lasting approximately 45 minutes each were conducted with participants. Online questionnaires were available to the respondents who preferred to complete them on their own. The interview guide included open-ended questions designed to elicit detailed responses to CVD experiences. Observations were conducted in two phases: initial visits to document the R&D and commercialization environment, followed by targeted observations of commercialization activities based on preliminary interview insights. This phased approach allowed adaptive data collection to respond to the emerging themes. To ensure the validity of our findings, we triangulated data from the interviews, observations, and government R&D databases. This entailed cross-verifying information on CVD determinants across these sources, thereby enhancing the reliability of our results. Discrepancies were addressed through follow-up interviews and additional targeted observations to confirm or clarify initial findings.

The study's multifaceted approach provided a comprehensive view of CVD determinants and commercialization trends. This methodology allows for a rich exploration of the complex interactions between various stakeholders in the technopreneurship landscape (Noeh et al., 2023). By incorporating the perspectives of researchers, innovators, and techno-business actors, this study captured diverse insights that contribute to a better understanding of CVD in real-world settings.

Furthermore, the chronological organization of the synthesized information facilitated the identification of trends and patterns over time, thereby providing valuable insights into the

evolution of technopreneurship research and development. The collected data were supplemented with information from public and government databases. This method enables researchers to interpret their findings and is highly relevant to empirical studies based on observations or experience (Mihas, 2019; Lester et al., 2020).

### ***Data analysis***

For quantitative data, descriptive statistics were used to summarize participant demographics and responses to the structured questionnaire items. Cross-tabulation was then applied to explore the relationships between the identified themes and the quantitative indicators of CVD impact. Ensuring the accuracy of the collected data involved verifying the completeness and consistency of the questionnaires. The data were then inputted into Microsoft Excel, organized, and thoroughly cleaned before analysis using the Statistical Package for Social Scientists (SPSS) 26.0.

Qualitative data from the interviews were analyzed using thematic analysis, where initial codes were generated from a subset of transcripts and iteratively refined as additional data were coded. A content analysis tool that enabled the reduction of qualitative data through codification, theme development, and result reporting (Mihas, 2019; Lester et al., 2020) was used. The documents were read, evaluated, and synthesized to pinpoint the factors, stakeholders, and circumstances or settings that promote innovation within the ecosystem. The notes from each phase were combined to develop the different codes. Next, the codes were collated by naming each phase, the codes from each phase were summarized, and themes were assigned to the codes. Finally, the themes were summarized to produce the results of the study. An explanation-building procedure was employed in the cross-case analysis (Plotz, 2020) to gain further insights into the determinants of CVD. The synthesized information was organized into chronologically arranged matrices to aid in drawing the conclusions.

## **Results and Discussion**

### **Innovation and commercialization activities of participating firms**

Firms can enhance their competitive advantage, drive growth, and sustain market presence by investing in innovation and commercialization initiatives (Lenihan et al., 2023). This comprehensive approach presents a dynamic framework for understanding the evolving technological landscape. By integrating information from diverse sources and stakeholders, this

study elucidates the complex interplay between various ecosystem actors. This multifaceted analysis identifies current trends and challenges while anticipating future developments, potentially guiding strategic decision making in both the public and private sectors.

**Table 1:** *Participants' innovation and commercialization activities*

<b><i>Innovation and commercialization activities (n=71)</i></b>	<b>Percent (%)</b>
Research and development	24.6
Engineering, design, and other creative works	6.9
Marketing and brand equity	13.7
Intellectual property protection	17.7
Employee training	16.5
Software and database development	4.8
Acquisition or lease of tangible assets	4.4
Innovation management	10.5
Others	0.9

The study findings indicate that firms reported that R&D is a critical aspect of their innovation and commercialization efforts, with 24.6% of respondents indicating this to be the case (Table 1). R&D is crucial for driving innovation within a firm by conducting systematic research, experimentation, and inventing new products, processes, and services (Crowley & McCann, 2018; Saka-Helmhout et al., 2020). R&D investment enables firms to remain competitive, adapt to market changes, and develop innovative solutions to meet customer needs.

This study found that approximately 18% of the surveyed firms granted exclusive rights to their ideas through intellectual property (IP) related activities. Firms can maintain a competitive advantage and generate revenue by protecting their ideas, technologies, and brand identity through IP protection (Rajapathirana & Hui, 2018; Kesselring et al., 2023). This research highlights the importance of investing in R&D and safeguarding IP rights to promote innovation and commercialization among businesses.

Approximately 16.5% of the firms surveyed engaged in collaborative staff training with academic institutions, research organizations, and other firms (Table 1). This collaboration can lead to knowledge exchange, access to specialized skills, and an expanded research scope (Abbas et al., 2018; Zhu et al., 2020). By joining forces, firms can reduce costs, share expertise, and accelerate the research and commercialization process. This study reveals that a substantial proportion of firms (13.7%) invested in marketing and branding efforts to develop unique and differentiated

products or services that satisfy customer needs and provide superior value. In doing so, businesses can attract more customers, build brand loyalty, and expand their market share.

The survey results showed that many firms engaged in innovation management (10.5%), engineering design (6.9%), and software development (4.8%) to enhance their products, processes, and efficiency (Table 1). Through continuous development, firms can identify areas for improvement and create new products or services to meet the changing market needs and improve their competitiveness (Barasa et al., 2017; Hussen & Çokgezen, 2022). Such activities are essential for firms to remain competitive and to offer better products and services. Continuous development is necessary to remain competitive and to offer better products and services.

The study indicated that only a small proportion (4.4%) of the firms engaged in acquiring or leasing tangible assets. These activities may lead to new market opportunities and offer various options. By exploring new technologies and emerging trends, firms can discover untapped or specialized markets, according to Crowley and McCann (2018) and Avenyo et al.(2021). Learning about customer preferences, behavior, and future demands through market research helps firms leverage emerging trends and expand their businesses.

### **Determinants of the commercialization valley of death among researchers, innovators, and techno-business actors**

Market-focused aspects significantly affect technopneurship outcomes by ensuring a viable market and meeting customer needs. Market research is essential for guiding firms toward successful innovation strategies (Hogan et al., 2022). Analyzing consumer trends and preferences allows companies to tailor their offerings to evolving demands, identify growth areas, and reduce the risk of unsuccessful technopneurship.

#### *Knowledge, competences, and expertise*

A firm's success depends on its knowledge and expertise (Atiase et al., 2020; Kesselring et al., 2023). In this study, 12.1% of the surveyed firms identified knowledge, competencies, and expertise as determinants of CVD (Table 2). According to research, a product with advanced technology may not always perform better than a product with less technology but effective management and marketing. Uganda has a long history of business practices and is known for its unique products (Fashina et al., 2018; World Bank, 2021). Our findings suggest that individuals with strong technical skills and experience in Uganda's knowledge-based economy oversee the

startups and techno-business firms in the country. Management and marketing expertise is often overlooked in favor of technical professionals, who prioritize technological advancements over effective communication with target clients. Firms that employ personnel with diverse backgrounds and expertise are better equipped to address this challenge and develop successful solutions to genuine problems.

**Table 2: Determinants of commercialization valley of death**

<b>Determinants of commercialization valley of death (n = 71)</b>	<b>Percent (%)</b>
Knowledge, competences, and expertise	12.1
Value proposition and investment profile	11.4
Policy environment	9.1
Product acceptance and awareness	8.6
Existing legal structure	8.4
Market size and related issues	8.3
Enterprise support schemes	8.0
Techno-based indigenous technologies	8.0
Availability of skilled personnel	6.9
Infrastructure support	6.2
Enterprise size and collaborative nature	5.1
Risk at the enterprise level	4.2
Disruptive nature of the enterprise	3.6
Others	0.1

*Value proposition and investment profile*

A unique value proposition is crucial to a product's success, as noted by Abbas et al. (2018) and Zhu et al. (2020). This proposition can take the form of enhanced efficiency, productivity, or performance, thereby providing users with additional advantages. According to this study, 11.4% of the surveyed firms identified value propositions and investment profiles as determinants of CVD (Table 2). Although technology has the potential to solve problems and generate positive economic impact, it is unlikely to succeed financially if people are unwilling to pay. Furthermore, such technologies struggle to gain the trust and support of investors seeking reasonable returns on their investment. Many products in Uganda have failed to gain market share because of entrepreneurs' poor management of business obstacles (World Bank, 2021). This issue is exacerbated when firms do not consider customer feedback during their product development.

### *Policy environment*

A well-balanced regulatory framework and government assistance programs are essential for promoting innovation adoption (UNCTAD, 2020; Aktar et al., 2021). In Uganda, 9.1% of the firms identified the policy environment as a determinant of CVD (Table 2). Although Uganda has made notable progress in becoming a significant market player through effective policies and processes that foster growth, concerns have been raised regarding the lack of a comprehensive and consistent policy approach. Appropriate policies implemented by the government are crucial for creating favorable conditions that drive technological advancement (Uyarra et al., 2020; Aktar et al., 2021).

### *Product acceptance and awareness*

The need for technological advancement in Uganda is primarily driven by social issues, as indicated by Fashina et al. (2018) and Atwine et al. (2023). According to the survey, 8.6% of the firms view product acceptance and awareness as determinants of CVD (Table 2). Addressing the high cost of adoption is essential for overcoming this barrier to innovation development and adoption. Several researchers have argued that a product's value in the eyes of customers determines its price (Crowley & McCann, 2018; Kim et al., 2019; Avenyo et al., 2021). To justify the higher prices of advanced technology, it is essential to emphasize its benefits, which outweigh the increased costs to users. Ugandan society's focus on enhancing social conditions and well-being makes it crucial to raise public awareness and embrace innovation for successful commercialization.

### *Existing legal structure*

According to the Global Entrepreneurial Monitor (GEM), Uganda has a favorable legislative environment that supports entrepreneurial activity (GEM, 2022). It outperforms other countries in providing government support for entrepreneurial initiatives, business creation, and development. However, 8.4% of the surveyed firms identified existing legal structure as a determinant of CVD (Table 2). Although the regulatory environment is generally stable and supportive of firms, there is room for improvement in the technological licensing process, which is complex and involves numerous procedures and standards (Fosci et al., 2019; CHANE & Atwal, 2023). Enhancing Uganda's legal framework would enable firms to accelerate the commercialization of technological innovation.

### *Market size and related issues*

Uganda's technological innovation market growth is influenced by global demand for modern technology and social transformation. Advanced technology, technical talent, and support infrastructure are opportunities in Uganda. The survey found that 8.3% of the surveyed firms identified market size and related issues as determinants of CVD (Table 2). However, Uganda's limited domestic market and lack of widespread technological breakthroughs pose challenges. According to Fashina et al. (2018) and World Bank (2021), the commercialization of technology in Uganda requires adjustments to infrastructure and consumer behavior. Therefore, deliberate effort is required to meet this demand. Domestic procedures and legislation can promote and facilitate the use of new technology and firms can receive assistance when entering foreign markets. Techno-business firms with substantial market knowledge, technological expertise, and a forward-thinking mindset dominate the Ugandan sector (NPA, 2020; World Bank, 2021).

### *Enterprise support schemes*

Techno-business firms in Uganda's technology sector lack resources, and small firms require additional funding to transform their concepts into significant innovations. The study indicated that 8% of the surveyed firms identified enterprise support schemes as determinants of CVD (Table 2), aligning with the perspectives of numerous researchers who emphasize the significance of finance for businesses as a crucial factor for their continued operation. While some firms receive assistance from organizations such as the Uganda Development Bank (UDB), obtaining funding, especially from later-stage firms, remains a significant challenge. Studies by Kim et al. (2019) and Zhu et al. (2020) emphasize the importance of adequate funding at all stages, including R&D and the intermediate phase before the market launch. Improving the lengthy process of providing financial assistance through centralized start-up support and single allocation disbursements can address this challenge.

### *Techno-based indigenous technologies*

This study analyzed the role of indigenous technology in promoting sustainable economic growth, preserving cultural diversity, and improving the livelihoods of local communities. It was found that 8% of the surveyed firms identified the inappropriate use of indigenous technologies as determinants of CVD (Table 2). Indigenous technologies can play a significant role in commercializing inventions and contributing to economic growth, social progress, and cultural

preservation (Ongâ & Abbey, 2019; NPA, 2020). Uganda's rich cultural diversity and traditional knowledge systems provide a promising platform for the commercialization of indigenous innovations. Traditional farming methods such as agroforestry, crop rotation, and organic farming offer sustainable alternatives to conventional techniques that benefit the environment. Additionally, commercializing indigenous medical knowledge can preserve traditional therapeutic practices and provide economic opportunities.

#### *Availability of skilled personnel*

Collaboration among techno-business firms, government agencies, and research institutions is crucial for technopreneurship in Uganda, as emphasized by Abbas et al. (2019) and Zhu et al.(2020). Among the firms surveyed, 6.9% identified the availability of skilled personnel as a determinant of CVD (Table 2). To promote firm growth and encourage local inventions, the government should actively embrace new technologies and leverage the limited local markets. This approach functions as a platform for real-time product showcasing and advertising to clients and stakeholders as well as a testing and refinement tool. Government support for industrial collaboration and international partnerships can further enhance these efforts. The Uganda Cluster Program has demonstrated significant success in promoting technology integration and utilization in the domestic market (Ecuru et al., 2014; Mulumba et al., 2017).

#### *Infrastructure support*

Techno-business firms require access to incubation facilities and infrastructure support (Kwesiga, 2019; Zhu et al., 2020). Of the firms surveyed, 6.2% identified infrastructure support as a CVD determinant (Table 2). Incubators, accelerator programs, research groups, and facility parks can provide various types of assistance (Abbas et al., 2018; Kwesiga, 2019). Opportunity exists in offering cost-cutting, expert-driven solutions in countries such as Uganda, which is known for its innovative culture and its technical universities. As bio-based firms grow in size, there is a need for continuous network support.

#### *Enterprise size and collaborative nature*

Firms must strive for optimal harmony between their assets and capabilities to thrive in uncertain and resource-intensive environments, as highlighted by Abbas et al. (2019) and Atwine et al.(2023). According to a survey, 5.1% of the surveyed firms identified enterprise size and

collaboration as determinants of CVD (Table 2). Collaboration enables firms to share resources and information, and access new markets and technology, leading to cost savings, increased sales, and improved product value. Collaboration with organizations in related fields can help techno-business firms avoid direct competition and benefit from their shared expertise. As Abbas et al. (2019) and Atwine et al. (2023) indicate, establishing a strong international presence typically requires collaboration, which helps firms to overcome international expansion challenges.

#### *Risk at the enterprise level*

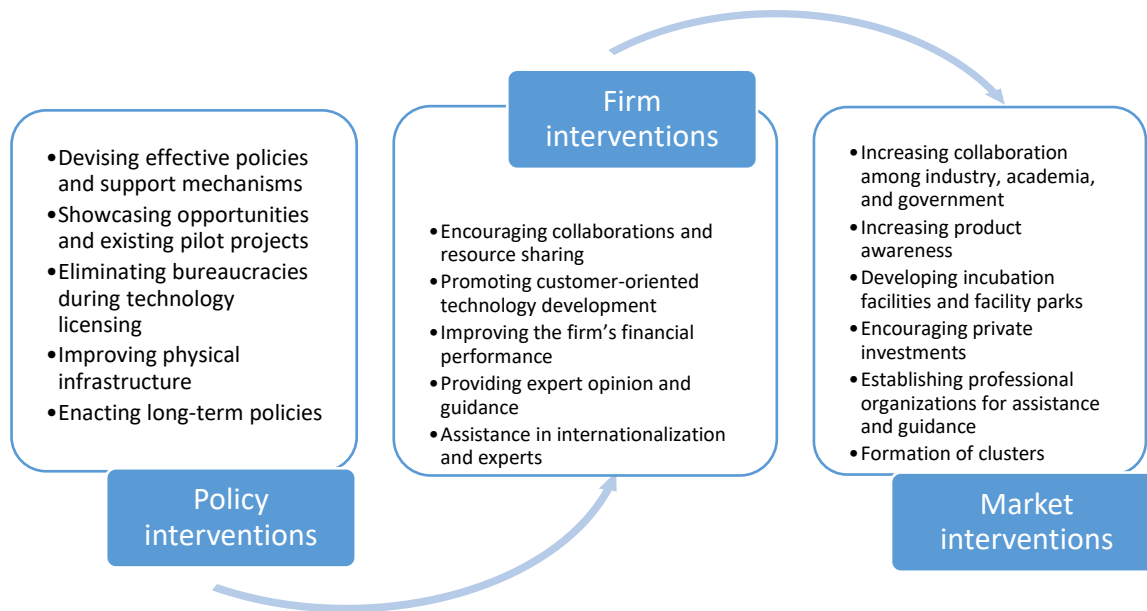
The success of entrepreneurship and venture development is not solely dependent on financial elements, market dynamics, and legal frameworks but also on the cultural and psychological characteristics of individuals within society and a firm (Kim et al., 2019a; Saka-Helmhout et al., 2020). As indicated in this study, 4.2% of the surveyed firms in Uganda identified risk at the enterprise level as a determinant of CVD (Table 2). Firms willing to take risks and explore new territories are more likely to succeed in their current or future markets. A firm's ability to take risks is influenced by various factors, including experience, behavior, personal mentality, social influences, and the overall environment.

#### *Disruptive nature of the enterprise*

Industry disruptions caused by technological advancements, shifting customer preferences, or innovative strategies can present challenges and opportunities for businesses attempting to introduce new innovations. In Uganda, 3.6% of the surveyed firms cited the disruptive nature of the enterprise as a determinant of CVD (Table 2). Firms that disrupt the market often attract many participants, leading to heightened competition from both new market entrants and established competitors who continuously introduce innovative products or services. This increased competition poses a challenge for firms to differentiate between themselves and achieve market dominance (Crowley & McCann, 2018; Rajapathirana & Hui, 2018). To succeed in this environment, businesses must possess greater distinction, scalability, and marketing acumen, which may also elevate barriers to the entry of new ideas. According to Atwine et al. (2023), firms must continuously enhance their offerings to remain competitive. Failure to adapt may result in a loss of market share or obsolescence of firms.

## Intervention framework at policy, firm and market levels to bridge the commercialization valley of death

Firms often face significant challenges when converting R&D into profitable products. To address this, we propose a comprehensive framework integrating policy, firm, and market-level interventions to bridge CVD and bring new technologies to the market. This framework acknowledges the interconnectedness of policy, firm strategies, and market dynamics in overcoming commercialization hurdles. By simultaneously tackling barriers at multiple levels, businesses can better navigate CVD and market innovative products (Jia et al., 2020). The proposed interventions aim to create a supportive innovation ecosystem, foster stakeholder collaboration, and provide the necessary resources for firms to make their R&D commercially viable.



**Figure III:** Intervention framework at policy, firm and market levels to bridge the commercialization valley of death

### ***Policy level interventions***

*Devising effective policies and support mechanisms:* Developing comprehensive funding rules is crucial for the commercialization of innovations (Zhu et al., 2020). The study findings indicate that 9.1% of the participants identified the policy environment as a determinant of CVD and that

the development of effective policies and support mechanisms would overcome it (Figure III). The government should establish funding programs and venture capital initiatives that primarily target creative startups and medium-sized businesses. Grants, tax incentives, low-interest loans, and investments in startups can all play essential roles in supporting innovation-driven businesses by providing financial aid to these entities.

*Showcasing opportunities and existing pilot projects:* Governments should invest in educational and skill development programs to foster an open workforce for new ideas (Abbas et al., 2019; Saka-Helmhout et al., 2020). The study findings indicate that 12.1% of the participants identified lack of knowledge, competence, and expertise as determinants of CVD, and that enhancing skill development among firms would overcome it (Figure III). Policymakers should consider promoting vocational training; science, technology, engineering, and mathematics (STEM) education; and entrepreneurship education to develop a talented workforce that can support firms' innovation and commercialization efforts.

*Eliminating bureaucracies during technology licensing:* According to Saka-Helmhout et al. (2020) and Aktar et al. (2021), it is crucial to develop policy frameworks that are both predictable and adaptable to streamline the technology licensing process and reduce bureaucratic hurdles. The study findings indicate that 8.4% of the participants identified hindrances in the existing legal structure as determinants of CVD, and that eliminating bureaucracy during technology licensing would overcome it (Figure III). The government should establish clear and transparent regulations, along with a predictable approval process to remove ambiguity and encourage businesses to invest in creative projects.

*Improving physical infrastructure:* Physical infrastructure acts as a controlled environment in which firms can experiment with and confirm the effectiveness of new products, services, and business models (Kwesiga, 2019; Kolade et al., 2021). The study findings indicate that 6.2% of the participants identified lack of infrastructure support as a determinant of CVD and that improving physical infrastructure would overcome it (Figure III). By collaborating with governments and regulatory agencies, firms can provide necessary physical infrastructure, allowing them to navigate complex regulations and showcase the feasibility of their ideas without having to comply.

*Enacting long-term policies/support schemes:* According to Perry (2020) and Kurpayanidi (2021), governments must routinely assess and modify their policies to foster innovation and commercialization effectively. The study findings indicate that 8% of the participants identified a lack of enterprise support schemes as a determinant of CVD and that enacting long-term policies/support schemes would overcome it (Figure III). This may involve the implementation of new incentives and financing structures to support policy development and to adjust existing policies.

### ***Firm level interventions***

*Encouraging collaboration and resource sharing:* According to Shakeel et al. (2017) and Abbas et al. (2019), partnering with strategic businesses can help overcome various commercialization hurdles. Study findings indicate that 5.1% of the participants identified lack of collaboration as a determinant of CVD and that establishing partnerships and sharing resources would overcome it (Figure III). These collaborations enable access to resources such as production capabilities, distribution networks, and marketing expertise. Firms can enhance their marketing capabilities for innovative products by combining the specialized knowledge of multiple businesses.

*Promoting customer-oriented technology development:* Firms must comprehend their clients' requirements, preferences, and areas of discomfort to achieve commercialization success (Kim et al., 2019; Bakhtiar et al., 2020). The study findings indicate that 8.6% of the participants identified a lack of product acceptance and awareness as a determinant of CVD, and that promoting customer-oriented technology development would overcome it (Figure III). Firms should conduct market research, establish channels for obtaining consumer feedback, and engage with potential customers during product development to guarantee customer-centric development. By aligning their products with client needs, firms can enhance their prospects for commercialization.

*Improving a firm's financial performance:* Access to sufficient financial resources is crucial for overcoming obstacles specific to firms in the commercialization of technological innovations. According to Kim et al. (2019) and Zhu et al. (2020), firms should explore alternative funding sources such as venture capital, investors, government subsidies, and crowdsourcing. The study findings indicate that 4.2% of participants identified risk at the enterprise level as a determinant of CVD, and that encouraging better financial performance and management would overcome it

(Figure III). Having adequate capital allows firms to invest in R&D, scale up manufacturing, and effectively market and disseminate innovation.

*Providing expert opinion and guidance:* Being responsive to market conditions with flexibility and agility can help firms manage barriers and maximize the commercialization potential of their innovations, as highlighted by Saka-Helmhout et al. (2020) and Avenyo et al. (2021). The study findings indicate that 12.1% of the participants identified a lack of knowledge, competence, and expertise as determinants of CVD, and that seeking expert opinions and assistance would overcome it (Figure III). This approach enables firms to gauge market demand, obtain inputs from early adopters, improve their products/services, and make the necessary adjustments. Firms must regularly assess their commercialization efforts and be adaptable to overcome current challenges. They should monitor market trends, competitors, and consumer feedback to identify emerging obstacles, and adjust their strategies accordingly.

*Assistance in internationalization and experts:* According to Avenyo et al. (2021), the success of commercializing products depends on a firm's necessary skills and resources, such as a culture of innovation and entrepreneurship, skilled and motivated employees, and effective management procedures. The study findings indicate that 12.1% of the participants identified a lack of knowledge, competence, and expertise as determinants of CVD, and that seeking internationalization support would overcome it (Figure III). Firms must invest in employee training and development and create an environment that encourages innovation to overcome internal hurdles and improve commercialization efforts. A clear strategy for bringing ideas to the market will enable the firm to efficiently navigate obstacles and successfully commercialize its products and services.

### ***Market level interventions***

*Increasing collaboration among industry, academia, and government:* Firms must establish partnerships with strategic partners, including industry, academia, and government, to leverage their market expertise, distribution networks, and client bases (Kim et al., 2019; Saka-Helmhout et al., 2020). Study findings indicate that 5.1% of the participants identified lack of collaboration as a determinant of CVD, and that increasing collaboration between industry, academia, and the government would overcome it (Figure III). Collaboration with key stakeholders, including

industry, academia, and the government, can provide access to resources, networks, and knowledge, which can help overcome the obstacles to market entry.

*Increasing product awareness:* According to Kim et al. (2019) and Avenyo et al. (2021), a robust marketing and branding strategy is essential for increasing awareness, stimulating demand, and establishing market confidence. The study findings indicate that 8.6% of the participants identified a lack of product acceptance and awareness as a determinant of CVD, and that enhancing product awareness would overcome it (Figure III). Firms must articulate the value propositions of their innovations by highlighting their benefits, characteristics, and distinctions. Furthermore, firms must use digital marketing channels and social media platforms to reach a broader audience.

*Developing incubation facilities and facility parks:* Incubation centers and facility parks serve as venues for firms to launch pilot programs and test products in designated areas, enabling them to evaluate market response, collect data on product performance, and gain insights into customer feedback and market demand (Kwesiga, 2019; Zhu et al., 2020). The study findings indicate that 6.2% of the participants identified a lack of infrastructure support as a determinant of CVD and that establishing incubation facilities and facility parks would overcome it (Figure III). These facilities facilitate product iterations and refinement, allowing firms to make the necessary adjustments before scaling up. Firms must design their innovations with scalability to ensure that they meet the expanding market needs without compromising quality or performance.

*Encouraging private investments:* Private investments are a vital source of financing for firms during the commercialization phase, according to studies conducted by Barasa et al. (2017), Kim et al. (2019), and Bakhtiar et al. (2020). The study findings indicate that 11.4% of the participants identified a low investment profile as a determinant of CVD, and that promoting private investments would overcome it (Figure III). Firms can explore various funding options including venture capitalists, angel investors, government grants, and crowdfunding platforms. The availability of private investments can be a critical factor in helping firms overcome market-centric challenges and successfully commercialize their innovations.

*Establishing professional organizations for assistance and guidance:* Professional organizations are essential for helping firms understand and adhere to industry-specific regulations and

standards, as highlighted in Saka-Helmhout et al. (2020) and Hussen and Çokgezen (2022). The study findings indicate that 12.1% of the participants identified lack of knowledge, competence, and expertise as determinants of CVD and that establishing professional groups for support and advice would overcome it (Figure III). Firms must collaborate with regulatory agencies early in the development phase to ensure compliance with the safety, quality, and legal criteria. Firms must validate the demand for their inventions by connecting with potential consumers, gathering feedback, and making the necessary adjustments to meet market demands.

*Formation of clusters:* Clusters enable firms to maintain flexibility and responsiveness to changing market requirements and trends, as demonstrated in the studies conducted by Kim et al. (2019) and Avenyo et al. (2021). The study findings indicate that 8% of the participants identified a lack of enterprise support schemes as a determinant of CVD and that the formation of clusters would overcome it (Figure III). To remain competitive, firms must continuously improve and innovate their products in response to customer feedback, market trends, and technological advancement. This requires a thorough understanding of the competitive landscape, including the existing solutions, pricing structures, and market positioning. It is essential to identify a firm's unique selling points and develop a compelling value proposition that differentiates it from competitors.

## **Conclusion**

### ***Theoretical implications***

Uganda's technology and innovation sector has advanced owing to increasing technological capabilities, demand for solutions, and government efforts to generate revenue, leading to significant progress. Despite these challenges, Technology Transfer Offices (TTOs) and government financing are crucial for bridging these gaps (Min et al., 2020; Suryati et al., 2020). While TTOs and government financing have supported innovation, research on their effectiveness in the specific socioeconomic conditions of Uganda remains limited. There is a need to explore how these entities navigate challenges unique to developing economies, including limited infrastructure and resource constraints. A Ugandan startup with a mobile payment app could stand out by integrating local microfinance institutions or vernacular languages, catering to the needs overlooked by its larger competitors (Bowman, 2019).

The current reliance on government financing raises concerns regarding sustainability and stifling innovation. Identifying and evaluating alternative financing models, such as private venture capital, crowdfunding, and public-private partnerships, would provide valuable insights into building a more resilient innovation ecosystem in Uganda. There is a notable absence of research on the effectiveness of entrepreneurial education and training programmes in Uganda. Investigating the impact of these programs on researchers' ability to commercialize innovations could bridge a significant gap in the literature and inform policy development (Takata et al., 2022; Kreiterling, 2023). Interdisciplinary research combining insights from economics, sociology, and technology studies could provide a holistic understanding of the barriers to innovation commercialization in Uganda. Such an approach would identify not only financial and technical challenges but also socio-cultural and policy-related barriers to innovation.

Additionally, researchers must adopt entrepreneurial strategies and institutions should create frameworks to support commercialization. Fostering technopreneurship in Uganda requires tackling the valley of death by enhancing TTO capabilities, leveraging government financing, and promoting an entrepreneurial mind-set among researchers. While identifying unique selling points and developing a compelling value proposition are crucial, they may not suffice in the fast-evolving technological sector. Some firms might succeed more by focusing on collaboration and open innovation (Asad et al., 2023), especially in resource-limited emerging markets such as Uganda. Additionally, over-reliance on government financing and TTOs could stifle true innovation by creating dependency, rather than fostering self-sustaining business models. Kruachottikul et al. (2023) suggest this approach should be supported by policies and infrastructure that encourage innovation and commercialization, addressing the specific challenges faced by techno-business firms and researchers.

### ***Policy implications***

While the study highlights the importance of policy support for technopreneurship, it also reveals a significant knowledge gap in the mechanisms of effective stakeholder coordination. Future policies should be informed by research that identifies successful models of stakeholder engagement in similar economies, detailing how these models can be adapted to Uganda's unique context. To bridge this gap, the government can establish a matching fund that incentivizes private sector investments in early stage technopreneurship ventures (Martins et al., 2023). For instance,

for every dollar invested by the private sector in early-stage technology firms, the government could match the percentage of this investment, thereby reducing the risk for private investors and encouraging more investments in the commercialization phase.

The identified gap in stakeholder coordination leads to fragmented support for technopreneurs, often resulting in duplicated efforts and inefficient resource use (Zhu et al., 2020; Noeh et al., 2022). By developing a national platform for innovation support that integrates the efforts of various stakeholders, Uganda can ensure a more cohesive support structure for technopreneurs, enhancing their ability to navigate CVD. Adopting international best practices in terms of tax incentives and R&D support offers a pathway for enhancing Uganda's innovation ecosystem. However, these practices must be carefully adapted to reflect the local context, such as the economic structure and business culture of Uganda. For example, tax incentives designed for high-tech sectors in developed economies may need adjustments to be applicable and effective for Uganda's emerging technopreneur sector.

The government and policymakers must ensure the effective enforcement of policies to boost the commercialization of technological inventions in Uganda. Despite political support for science, technology, and innovation (STI) development, a coherent coordination mechanism among stakeholders is missing (Bowman, 2019; Okwakol et al., 2022). Policymakers must address gaps in the research ecosystem and industry by enhancing innovation support. University research teams often develop new technology and risk overreliance on government grants and institutional resources without proper commercialization policies, industry partnerships, and viable business models (Martins et al., 2023). Strengthening policy execution, analysis, and amendment across policy cycles is crucial for transformational development, increased industrial output, and stronger private-sector linkages.

Policy recommendations for fostering technopreneurship in Uganda should align early-stage government investments with later-stage funding, promote public-private partnerships (PPPs), and adopt international best practices in tax incentives and R&D support (Zhu et al., 2020; Noeh et al., 2022). While increased support and policy coordination are often suggested, they may not tackle the fundamental innovation challenges in Uganda. Excessive government intervention can hinder private sector initiatives and lead to resource misallocation (Stubbs et al., 2022). Furthermore, the

heavy reliance on international best practices may not suit Uganda's unique socioeconomic context, resulting in misaligned policies. Policies should also focus on developing human capital and innovation infrastructure, which are essential for enhancing a nation's innovation capacity (Bowman, 2019; Kwesiga, 2019). Addressing these issues can help cultivate a more supportive ecosystem for researchers, innovators, and techno-business firms in Uganda.

### *Ideas for future research*

The proposed framework suggests a multifaceted approach to bridging CVD; however, the efficacy of these interventions in different industrial contexts within Uganda remains unexplored. Future research could examine the impact of these interventions in sectors such as healthcare, agriculture, and ICT, to identify sector-specific challenges and opportunities. While this study addresses technological and policy interventions, the role of cultural factors and entrepreneurial mindset in navigating CVD in Uganda is less understood and represents a critical area for future research. Future research should conduct sector-specific studies that investigate the unique commercialization challenges and opportunities within Uganda's emerging agri-tech, health-tech, and renewable energy sectors (Suryati et al., 2020; Noeh et al., 2022). This includes understanding the regulatory, market, and technological barriers specific to each sector, and identifying successful models of technopreneurship that have managed to bridge the commercialization gap.

Future research should examine the impact of digital innovation ecosystems, including the role of incubators, accelerators, and tech hubs in supporting technopreneurship in Uganda. This research could identify best practices for leveraging digital technologies to facilitate the commercialization process, enhance knowledge exchange, and foster collaboration between startups, academic institutions, and industry (Kwesiga, 2019; Samarasinghe et al., 2021). Subsequent studies should critically evaluate the impact of the current policy interventions on technopreneurship in Uganda. This involves assessing the effectiveness of government funding, tax incentives, and support programs in enhancing the commercial viability of innovations (Nahikiriza, 2023). Research should also propose evidence-based policy solutions that address identified gaps, such as the need for more targeted support for early stage technopreneurs and mechanisms to enhance public-private partnerships.

Future research could benefit from cross-country comparative studies analyzing how different countries have successfully addressed similar challenges in technopreneurship and commercialization. Such studies could identify transferable lessons and strategies that could be adapted to the Ugandan context, focusing on policy frameworks, innovation ecosystems, and support structures that facilitate the transition from research to the market. Longitudinal studies are needed to track the evolution of technopreneurship in Uganda, assess the long-term effectiveness of interventions, and how technopreneurs adapt to changing market dynamics and technological advancements. This research could provide insights into the sustainability of technopreneurial ventures and persistent barriers to commercialization (Son et al., 2022; Martins et al., 2023).

Future research could investigate the creation of a comprehensive commercialization ecosystem, universities' roles in technopreneurship, and the innovation potential of both large companies and tech startups. While examining technopreneurship models and innovation systems is beneficial, it may overlook the challenges in developing countries such as Uganda. Emphasizing university-driven commercialization might be less effective in regions with limited resources and infrastructure (Sendawula et al., 2023). Additionally, focusing only on open innovation and tech start-ups could neglect traditional industries, which remain vital to Uganda's economy. The impact of open innovation on Ugandan tech-startup culture also warrants further exploration. Such research could inform policies that promote entrepreneurship and foster an innovative culture that is essential for economic development (Srikanth et al., 2020; World Bank, 2021).

### ***Limitations of the study***

This study's reliance on qualitative and quantitative methods from a purposive sample of 71 participants may not fully capture the diversity of experiences and challenges across Uganda's techno-business sector. Future studies could employ a larger and more diverse sample to verify these findings and explore sector-specific dynamics in greater depth. While this study provides comprehensive insights into overcoming CVD among Ugandan techno-business actors, the specificity of the Ugandan context limits its generalizability. There is a need to explore the applicability of our findings to other developing countries, particularly to those with different regulatory frameworks and levels of technological advancement.

## Declarations

**Data availability statement:** The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

**Disclosure statement:** The authors declare no conflicts of interest.

**Author contributions:** All authors contributed to the writing of the manuscript, read and approved the final manuscript. RJ analyzed the datasets used for the study and drafted the manuscript, while JBK and NM reviewed and revised the manuscript

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## **PAPER VII**

# **A framework for commercialization of technological innovations in Uganda: an integrated firm-specific, market-centric, and policy-related model**

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## **Abstract**

Uganda has made progress in its input to innovation, research, and development (R&D), but it still faces commercialization challenges. There is a need for scientists, researchers, and innovators to understand how to commercialize their ideas; however, the existing literature lacks an integrated framework. This study aims to develop a framework for innovation commercialization, highlighting firm-level barriers, market constraints, and policy solutions. The study employed a multiple-case and cross-sectional survey design, utilizing a subjective and qualitative research approach. Interviews were conducted with select techno-business enterprises, universities, research institutions, incubators/accelerators, and government bodies to gain insights and experience on innovation commercialization. Innovation commercialization barriers at the firm, market, and policy levels were assessed to generate strategies and measures to overcome them. The study introduces an innovation commercialization framework and identifies the key determinants of successful commercialization, including firm-level capabilities, market-driven product awareness, industry dynamics, and policy-related factors. The study emphasizes the need for support mechanisms and recommends policy reforms to foster a vibrant market for innovation commercialization in Uganda. A multifaceted approach is proposed, incorporating investments in R&D infrastructure, market access initiatives, and regulatory enhancements. Addressing structural barriers such as weak institutional support, limited financial access, and lack of coordination among innovation actors is essential to bridge the commercialization gap. Strengthening talent exchange programs, developing regional knowledge value chains, and prioritizing institutional reforms are key to improving commercialization efficiency.

**Keywords:** Commercialization, Framework, Innovation, Research and Development, Uganda

## Introduction

The development of science, technology, and innovation (STI) is essential for industrialization and advancement. STI transforms ideas into useful products, streamlines work processes, and enhances access to information and knowledge, thus contributing to economic competitiveness (NPA, 2020; Aktar et al., 2021; OECD, 2021). It also creates new businesses and industries that commercialize new products and processes, such as policy changes to add value to goods and services, agro-processing, technological product development, and commercialization. Investing in STI can lead to higher return on investment (ROI), with estimates of 30% and 50% in the private and social sectors, respectively. Despite these benefits, Uganda has not yet made significant investments in STI. Developed countries allocate 2-3% of their gross domestic product (GDP) to research and development (R&D). Therefore, it is crucial to prioritize STI in Uganda's socioeconomic development strategy (Mulumba et al., 2017; Bowman, 2019; World Bank, 2021).

Global developments have emphasized the need for enterprises to commercialize their ideas to compete or grow in the global market. These developments, as well as the increasing pace of creating and commercializing, have helped innovators succeed, while also raising the bar for competition. Successful commercialization can assist organizations in entering or creating new markets, contributing to their industry leadership and longevity. Previous research has linked a firm's competencies, human resource strategies, top management teams, and external environment to successful commercialization (Gbadegeshin, 2018; Bakhtiar et al., 2020). Uganda ranks 102 out of 129 countries in the 2020 Global Innovation Index, which places it in a disadvantageous position (Dutta et al., 2022). The country performs poorly in key transformative indicators such as technology readiness and innovation (NPA, 2020; Dutta et al., 2022). Uganda's gross expenditure on research and development (GERD) was only 0.4% of its GDP, which is significantly lower than African Union's recommended target of 1%. Additionally, the country's corporate R&D expenditure was only 0.01%, and only two out of 250 patent applications were filed (NPA, 2020; Sithole, 2020).

The government of Uganda (GOU) has implemented a strategy to promote economic growth and sustainable development by commercializing technological innovations, as outlined in the country's STI Policy (MFPED, 2009), the National Development Plan (MFPED, 2012), and Vision

2040(NPA, 2007). However, effective policies and strategies must be developed and implemented in the context of national innovation systems (Chaminade et al., 2018; Kurpayanidi, 2021). There is no agreement among management theorists and practitioners regarding the influence of commercialization decisions on market failures (Bakhtiar et al., 2020; Kruachottikul et al., 2023). The innovation and commercialization process is complicated and challenging, involving various entrepreneurial activities, from idea generation to product launch. However, only a small percentage of innovative ideas succeed and only 39% of executives believe that their firms are effective in commercializing new products or services. One-third of senior leaders view commercialization as one of their major challenges (Gbadegeshin, 2018; Kim et al., 2019).

Currently, there is a gap in the literature regarding a comprehensive framework for effectively commercializing inventions. A successful commercialization process is crucial to unlock the full potential of innovation, as demonstrated by the commercial success of products and their strategic significance for driving economic growth and development (Gbadegeshin, 2018; Upadhyayula et al., 2018). The lack of information about a country's innovation and commercialization processes hinders effective investments in STI and impedes the ability of policymakers and other stakeholders to develop initiatives that promote growth. This can result in the underutilization of well-intentioned STI programs and an underestimation of the value, relevance, and impact of technological innovation programs.

This study emphasizes the need for improvements at both the micro (technology-driven business enterprises) and macro (policies, regulations, and infrastructure) levels. It proposes a model framework to facilitate the efficient commercialization of technological innovations, thereby maximizing the potential of the STI value chain. This approach aims to enhance returns on investment and inform decision-making among firms, government agencies, and partner institutions concerning investments in Research and Innovation (R&I) to drive socioeconomic transformation. Successful innovation commercialization in Uganda requires a combination of strategic collaborations, dynamic business models, robust institutional frameworks, and tailored financing strategies (Kwesiga, 2019; Ogwang & Vanclay, 2021; Yan et al., 2024). These elements must be adapted to fit Uganda's innovation ecosystem, ensuring a seamless transition of technological innovation from conception to the market. A viable commercialization framework for Uganda should be multifaceted, incorporating technological entrepreneurship, adaptive

business models, and academic-industry linkages. In addition, the development of a supportive ecosystem including educational initiatives, financial incentives, and infrastructural support is crucial. A well-structured commercialization framework plays a transformative role in translating technological innovation into market-ready products, thereby fostering economic development and national progress (Kwesiga, 2019; Ogwang & Vanclay, 2021; Yan et al., 2024).

## Literature review

### *Innovation and Commercialization Context Indicators*

#### *Global Innovation Index*

The Global Innovation Index (GII) ranks world economies according to their innovation capabilities. According to NDP III, Uganda seeks to increase its Global Innovation Index from 25.32 to 35 between 2020 and 2025. Over the past three years, Uganda has performed better in terms of innovation inputs than output. However, the aggregate ranking of Uganda remains low (NPA, 2020; Dutta et al., 2022). This is reflected in Table 1, which shows the rankings of Uganda and other East African Community (EAC) countries (Dutta et al., 2017, 2018, 2019, 2020, 2021, 2022, 2023). Uganda's most recent GII score is significantly below the average score of 33.86 for the thirty-four upper middle-income countries included in the 2023 World Intellectual Property Organization (WIPO) Global Innovation Index Report. This level of technological innovation performance, with an absolute overall GII score in the range of 33–36, is equivalent to the scores of countries such as Brazil, Colombia, Costa Rica, Iran, Serbia, and South Africa, as summarized in Dutta et al. (2023). However, as shown in Table 1, Uganda's GII scores did not improve and fell further behind those of benchmark countries.

**Table 1:** *Global innovation index scores, 2017 – 2023, Source: GII 2017-2023*

<b>Country</b>	<b>2017</b>	<b>2018</b>	<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>	<b>2023</b>
<b>Top score</b>	67.69	68.40	67.24	66.08	65.50	64.60	67.60
<b>Uganda</b>	<b>26.97</b>	<b>25.32</b>	<b>25.60</b>	<b>20.54</b>	<b>20.00</b>	<b>15.70</b>	<b>16.00</b>
<b>Kenya</b>	30.95	31.07	31.13	26.13	27.50	22.70	21.20
<b>Rwanda</b>	27.36	26.54	27.38	25.06	23.90	18.70	20.60
<b>Lowest score</b>	15.64	15.04	14.49	13.56	15.00	11.60	10.30

According to Dutta et al. (2023), Uganda's GII score exhibits a few areas of strength, such as the regulatory environment and general infrastructure, which mainly comprise electricity access and communication infrastructure, including roads, but not STI-specific infrastructure or innovation linkages. The positive aspects of the latter include the percentage of R&D funding from abroad and the linkages between industry, researchers, and innovators. However, their scores revealed weaknesses in online creativity, knowledge diffusion, knowledge absorption, knowledge workers and levels of technology investment.

### *Technology Achievement Index*

The Technology Achievement Index (TAI) is defined as a function of four indices: technology creation, human skills, diffusion of recent innovation, and diffusion of old innovation. Evidence suggests that the capacity to deploy technologies in Uganda is low because of weak R&D capabilities for new technology creation in the country. This reality points to an understanding of the strategies for acquiring existing technologies that may either be new to the world or may only be new to Uganda. According to UNCST (2016a) and NPA (2020), Uganda is classified as a net importer of technology with a TAI of 0.24, placing it in the same category as other developing technologically marginalized nations. The limited technological efforts of domestic industries, coupled with the inability to convert public R&D efforts into productive improvements due to difficulties in utilizing and diffusing information and skills, contribute to this situation, as supported by Incekara et al. (2017) and Amballoor and Naik (2021). This challenge is compounded by the absence of a strong domestic STI human capital base. In 2010, at the start of NDP I, Uganda's overall TAI score was 0.15, which placed it in the lowest category of countries that made marginal use of technology. This poor ranking was largely due to low scores for new technology creation, the diffusion of existing technologies (as measured by low levels of Internet hosting and low levels of medium- and high-technology exports), and human skills. However, Uganda's 2010 TAI ranking for the diffusion of old innovations was relatively high, reflecting good performance in electricity consumption per capita and the number of telephone subscribers. The targets set for TAI in the NDP IV (2025/26-2029/30) and Uganda Vision 2040 aim to reach 0.5 by 2040 (NPA, 2007, 2020).

### *Gross Expenditure on Research and Development*

Gross Expenditure on Research and Development (GERD) is the main aggregate statistic used to describe a country's Research and Development (R&D) activities and covers all expenditures for R&D performed in the economy. R&D comprises creative and systematic work undertaken to increase the stock of knowledge and devise new applications of available knowledge, as defined in the OECD Frascati Manual of 2015. Uganda's GERD accounts for 0.4% of its Gross Domestic Product (GDP). Moreover, corporate R&D investment is notably low, accounting for only 0.01% of GDP, and only two out of 250 patent applications were filed in the country (NPA, 2020; Sithole, 2020). While R&D expenditure as a percentage of GDP has fluctuated between 0.2% and 0.5% over the past five years, most of this funding originates from external sources (UNCST, 2016b). This level of spending falls short of the recommended minimum of 1% of GDP for R&D by the African Union (African Union Commission, 2014). Investments in global R&D in 2020 continued to grow at a rate of 3.3% from 6.1% in 2019. Business R&D expenditures, the most significant component of total global R&D, grew by 3.5% in 2020 from 6.6% in 2019. This gap in research spending limits Uganda's ability to engage in a highly competitive global knowledge ecosystem.

### *The Triple Helix Model's Role in Innovation Commercialization*

The Triple Helix model characterizes the connection between knowledge creators, knowledge users, and the government and their involvement in a knowledge-based economy (Abbas et al., 2019; Cai & Etzkowitz, 2020). The Triple Helix model elucidates the interaction, reciprocal support, and collaborative development among universities, industries, and governmental entities, with academic institutions assuming an expanded role (Noya & Taneo, 2023; Wang et al., 2024). Within a Triple Helix framework, the functions of these three spheres evolve, enabling each to adopt the responsibilities of others in specific contexts (Cai & Etzkowitz, 2020; Zhuang et al., 2021). This paradigm facilitates the integration of functions and the establishment of intermediary or connecting organizations, as collaboration between universities, industries, and the government engenders flexibility in institutional boundaries. Knowledge-generating entities include universities, research institutes, scientific academies, and other science and technology-related agencies (Noya & Taneo, 2023; Wang et al., 2024). The governmental sphere encompasses science and technology (S&T) policy-making bodies and legal and regulatory organizations, while

knowledge-consuming (industry) entities include for-profit and nonprofit manufacturing and service sectors.

Effective hybrid organizations, specifically incubators, have been recognized for their capacity to facilitate collaboration among academic institutions, industrial entities, and governmental bodies (Noya & Taneo, 2023; Wang et al., 2024). These organizations contribute significantly to the survival and competitive success of innovative clusters, which drive economic development. Interconnected relationships among entities such as education, research, development, industries, and financial institutions characterize innovative clusters. This creates a cycle of innovation and entrepreneurship (Cai & Etzkowitz, 2020; Zhuang et al., 2021). A cluster is the geographical concentration of interconnected yet competing businesses, suppliers, service providers, and associated institutions (Gerli et al., 2022). The concept of clusters gained prominence in public policy discourse during the early 1990s when it was adopted by professionals across the public, private, and academic sectors (Noya & Taneo, 2023; Wang et al., 2024). Governments worldwide have embraced this concept to promote national and regional competitiveness, innovation, and growth (Kurpayanidi, 2023).

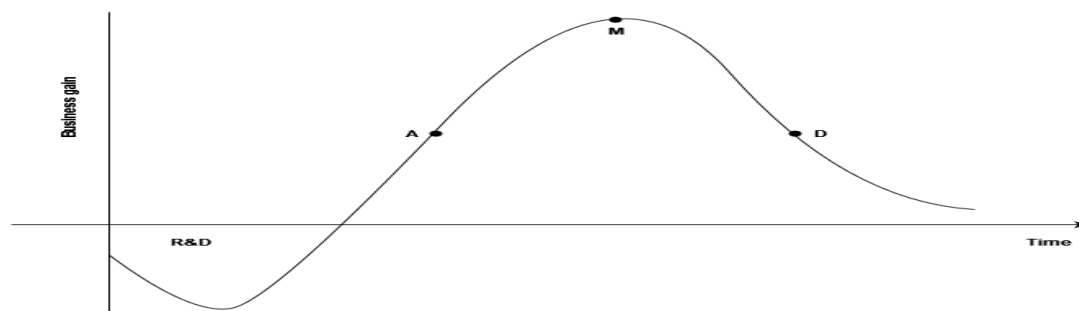
In developing countries, particularly in Africa, the rate of progress has been comparatively slower than that in developed and newly industrialized countries in Asia. Consequently, analyzing and deriving insights from benchmarks can enhance collaboration and mutual benefits among existing Triple-Helix actors. Clusters are vital for facilitating the dissemination of knowledge among businesses by bringing together neighbouring producers, suppliers, buyers, firms, and other stakeholders in the same geographical area, thereby fostering collaboration and creating mutually beneficial relationships around a specific functional niche. Cluster initiatives entail joint efforts from private industry, public authorities, and academic institutions to enhance the competitiveness of a cluster. According to (Musabayana et al., 2023), small and medium-sized enterprises (SMEs) can benefit from clusters and networks by accessing skilled labour and shared business services. The physical proximity of stakeholders facilitates the development of formal and informal networks and systems. This propinquity enables an unrestricted exchange of knowledge and ideas among participants. These connections facilitate specialization, technological advancement, adaptability, creativity, and competitiveness (Asad et al., 2023). Clustering significantly influences

regional development, fostering collaboration between private and public entities for mutual benefits through governmental and local investments in initiatives such as innovation hubs, research parks, and technology transfer centres (Islam & Wahab, 2021; Gerli et al., 2022).

In Uganda, the concept of clustering remains nascent, with governmental bodies and educational institutions endeavouring to establish tripartite partnerships involving academia, industry, and the government in formulating policies and implementing university outreach programs (Nahikiriza, 2023). While Abbas et al. (2019) emphasize the critical role of government support in innovation commercialization, scholars have highlighted instances where excessive government intervention has stifled innovation (Zhu et al., 2020; Zhang et al., 2023). This discrepancy highlights the complex nature of government involvement in innovative ecosystems and underscores the need for a balanced approach. Despite extensive research on the impact of the Triple Helix model on innovation commercialization, there remains a lack of understanding of how it interacts with Uganda's local cultural and economic dynamics. This approach directly points to gaps and sets the stage for the relevance of this study.

### ***Technology lifecycle and commercial achievement***

As technology advances, the relationship between Technology Lifecycle (TL) and commercial success reflects the degree of commercial achievement over time. This serves as a benchmark for optimizing R&D resource allocation and predicting the timing of R&D investment based on potential product growth and expected market profitability (Byun et al., 2018; Lüdeke-Freund, 2020). While TL emphasizes development duration and expenditure on anticipated revenues, commercial success encompasses R&D costs incurred after a product's release. The TL consists of four distinct stages, as shown in Figure 1.

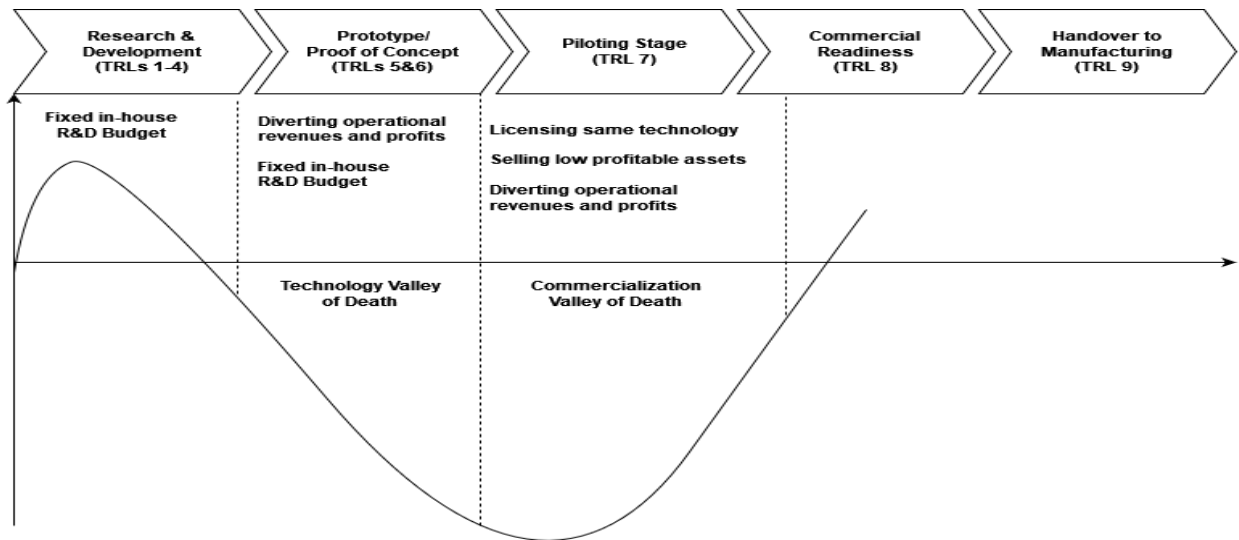


**Figure 1:** Relationship between technology lifecycle and commercial achievement (Byun et al., 2018)

In the initial phase, investment risk is typically associated with technological innovation as firms conduct R&D to identify the most promising projects. This timeframe witnessed the extensive allocation of resources towards R&D, aimed at assessing diverse market responses with a notably high probability of failure. The subsequent phase, signified by the attainment of development (point A), is characterized by the recuperation of invention expenditures and the prospect of rapid expansion, the proliferation of innovative products, and the establishment of competitive advantage by introducing the most advanced and efficient offerings. Around point M, the ensuing stage is characterized by a maturity period in which public acceptance of innovation is achieved, and competitors enter the market, resulting in supply exceeding demand and a gradual erosion of profits. After point D, the final phase is marked by a decline during which commercial gains transform into a zero-sum scenario because of the inability to sustain profit margins (Byun et al., 2018; Lüdeke-Freund, 2020).

### ***Technology readiness level***

Technological Readiness Level (TRL) is a qualitative assessment method that evaluates innovation maturity throughout the R&D process (Upadhyayula et al., 2018; Salazar & Russi-Vigoya, 2021). The first four TRLs involve understanding fundamental principles, developing an idea, and creating a proof of concept tested on a laboratory scale. TRLs 5 and 6 involve technological validation and demonstration in an industrial setting. TRL 7 denotes the demonstration of a prototype in an operational setting, whereas TRL 8 signifies the conclusion of development, with the system undergoing tests in an operational environment. TRL 9 indicates that the technology is ready for manufacturing and routine operation. According to Upadhyayula et al. (2018), the commercialization of technology results in either a hard or soft product with both quantifiable and intangible advantages. Financial assistance is necessary at all nine stages to advance promising innovations in the commercialization stage. Obtaining funding from private investors or banks can be difficult and requires navigating two "valleys of death" from TRL 1 to TRL 9.



**Figure 2:** Technology and commercialization valley of death (Upadhyayula et al., 2018)

### *Technology Valley of Death*

The Technology Valley of Death (TVD) phenomenon arises during stages TRL 5 and 6 (Figure 2.4). This occurs when a validated laboratory concept is immature for mass production on an industrial scale (Gbadegeshin et al., 2022; Son et al., 2022). To move their innovations from TRL 1 to TRL 4, researchers from academia, research laboratories, and start-up companies typically seek funding from state and federal agencies. However, to progress beyond TRL 4, securing financial support from private investors, including Venture Capitalists (VCs), is necessary. Unfortunately, many innovators fail to attract investor attention due to a lack of motivation or marketing resources. Many VCs are hesitant to invest in options that require a complex exit strategy, such as an Initial Public Offering (IPO), and are interested only in innovations that can move through TRL stages 5–6 and offer a quick ROI. Additionally, VCs may hesitate to invest in ventures that require high capital investment. According to expert analysis, four of the five innovative concepts fall into the TVD (Takata et al., 2022).

### *Commercialization valley of death*

The Commercialization Valley of Death (CVD) occurs early in science-based innovation when a lack of funding and support impedes a technology's continued development. This phase occurs between the invention and innovation stages or between the technical invention or market recognition of an idea (Huizingh & Biemans, 2020; Ellwood et al., 2022). It is also characterized as an inability to progress from the technology demonstration phase to the commercialization

phase (Figure 2.4). Although terminology suggests that different innovation processes are essential, this phase occurs at a critical juncture in technological development, when foundational R&D is incomplete, and technology commercialization is not yet fully understood. However, these two processes overlap and inform each other.

Technology transfer across CVD may pose significant management challenges (Dean et al., 2022; Son et al., 2022). It is widely accepted that the initial stages of science-based innovation are characterized by uncertainty regarding technology and market understanding, and investment decisions are rarely based on a secure foundation. The inherent organizational complexity of this development phase contrasts with the two better-organized innovation functions surrounding it, namely, research and commercialization. Operations within distinct institutional frameworks accentuate the contrast between these two functions. Scientific research and commercial endeavours are governed by separate normative and cultural principles, exacerbating the disparity between their roles. Therefore, managing the transition between these logics is crucial to prevent differences from becoming a barrier to transferring technological knowledge (Al-Shaikh & Siddiqui, 2021; Takata et al., 2022). For example, discrepancies in IP-related cultural and normative logic can lead to conflicts in invention disclosure, patent licensing, and the ongoing use of IP in research.

Despite the growing body of research on CVD, there remains a substantial gap in the understanding of how firm factors influence the capacity of Ugandan techno-business firms to address CVD. Furthermore, the role of market-oriented elements, such as consumer preparedness and product-market alignment, has not been extensively investigated within Uganda's unique context. While the importance of technological expertise and research facilities is recognized (Everts & Drew, 2024; Sutarjo & Bajuri, 2024), there is limited understanding of how these factors interact with Uganda's distinctive market dynamics, such as consumer preferences for technological products and the target audience's digital literacy. Therefore, this lack of comprehensive knowledge impedes the development of targeted strategies to overcome the CVD challenges in Uganda.

Our research question, formulated based on the literature reviewed above, is as follows: How do drivers of innovation commercialization interact at the firm, market, and policy levels? This question aims to identify the firm-specific, market-centric, and policy-related factors that affect

the innovation commercialization process at the institutional level in Uganda. The answers to this question contribute to a better understanding of the barriers faced by institutions in Uganda when attempting to commercialize their innovations.

The literature review shows that various actors are involved in transforming innovation into marketable products or services. When conditions are conducive, interactions and learning among these actors occur, resulting in innovations that improve the productivity, commercial viability, and profitability of institutions. To achieve this, actors throughout the commercialization ecosystem must grasp the processes of commercializing innovations and overcome barriers to technology adoption and commercialization. However, the existing literature is deficient in empirical theory or an explanation regarding the barriers and associated measures that influence innovation commercialization in Uganda.

## **Method**

### ***Study approach***

According to Shakeel et al. (2017) and OECD/Eurostat (2018), a formal and subjective research approach was utilized to identify the factors influencing the commercialization of technological innovations. The study employed two primary design methodologies: a multiple-case design and cross-sectional survey design. The multiple-case design method enabled a comprehensive examination of the sectoral product commercialization systems selected as cases, as well as the application of multiple approaches (Holliday, 2014; Manly, 2015). The cases were analyzed sequentially using embedded units of analysis.

### ***Study population***

Participants were selected from techno-business firms, universities, research institutes, incubators, and government bodies based on the following inclusion criteria: a) involvement in at least one commercialization project within the last five years; b) holding a position that directly influences R&D decisions, such as project managers, principal researchers, or executives of institutions; and c) willingness to provide a detailed description of the innovation and commercialization process in their respective institutions. This inclusion criteria for participant selection ensured that the study gathered insights from individuals with first-hand experience in Uganda's innovation and

commercialization landscape. Participating institutions were broadly classified into four categories: knowledge generators, such as research institutions and universities; knowledge consumers, including techno-business firms and industry actors; government bodies; and support systems such as incubators and innovation hubs.

### ***Sampling method***

To ensure a representative sample, we calculated the required sample size using a standard formula based on the expected proportion of innovative firms and a confidence level of 95%. Study participants were recruited based on purposive sampling, a method designed to ensure an in-depth understanding (Ismail et al., 2017; Patton, 2002) of the factors that contribute to successful innovation commercialization and to align with the study's conceptual framework and research questions. Unlike random sampling, purposive sampling employs predetermined criteria to satisfy a specific objective, thereby minimizing the risk of bias (Pellikka & Malinen, 2014). This method allows inferences and explanations to be drawn from data. Participants from techno-business enterprises, universities, research institutes, incubators, and government bodies who participated in commercializing at least one product were selected based on their R&D-related innovation. Informants with sufficient experience and the ability to comprehensively describe the commercialization process in their respective firms (Pellikka & Malinen, 2014) were selected.

The sample size was determined using the following formula:

$$n = \frac{Z^2 \times [P \times (1-P)]}{\alpha^2} \quad (\text{Manly, 2015})$$

Where  $\alpha$  is the level of significance,  $e = 5\%$  [error],  $P = 0.917$  [% of entrepreneurs in Uganda] (NPA, 2020; Sithole, 2020), and  $Z = 1.96$  [Z-value].

$$\text{Taking } \alpha = 5\%, \text{ Thus } n = \frac{1.96^2 \times 0.917 \times 0.083}{0.05^2} = 116$$

The study sample size was a total of 116 participants.

### ***Data collection***

The study was initiated in 2023 and encompasses researchers, innovators, business owners, civil society practitioners, and government officials involved in innovation policy, financing, standards, and regulations, following Section 9.5 of the OECD/Eurostat (2018) guidelines (Oslo Manual, p.194). The investigation used questionnaires administered by the researcher or completed online by participants. A mixed-methods approach, integrating both participatory and survey-based methods, was adopted to conduct an overall study on a framework for the commercialization of technological innovations in Uganda. A total of 71 responses were collected from 116 participants, resulting in a response rate of 61%. The data collection instrument assessed the commercialization of innovations at firm-specific, market-centric, and policy-related levels.

### ***Data measurement and analysis***

A qualitative approach was applied to explore how technopreneurs comprehend, strategize, and manage activities related to innovation commercialization. Guided by the principles of flexible research design and triangulation where applicable (Yin, 2009), the study also integrated quantitative data to enrich the evaluation of innovation commercialization within the selected case firms. Data were integrated by verifying the completeness and consistency of the questionnaire responses. Where clarification was needed, additional information was requested from respondents.

Descriptive statistics were used to summarize participants' demographic characteristics and responses to the structured questionnaire. Cross-tabulation was then applied to examine the relationships between emerging themes and quantitative indicators associated with innovation commercialization outcomes. The data were first cleaned and organized using Microsoft Excel before analysis using SPSS 26.0.

Qualitative interview data were analyzed using thematic analysis. Initial codes were generated from a sample of transcripts and iteratively refined as more data were processed. Specialized content analysis software (MAXQDA) facilitated coding, theme extraction, and generation of analytical results (Mihas, 2019; Lester et al., 2020). Documents were reviewed and synthesized to identify key stakeholders, contributing factors, and contextual elements that support innovation

commercialization within the ecosystem. The data analysis process followed a structured, three-pronged approach (Mihas, 2019; Lester et al., 2020):

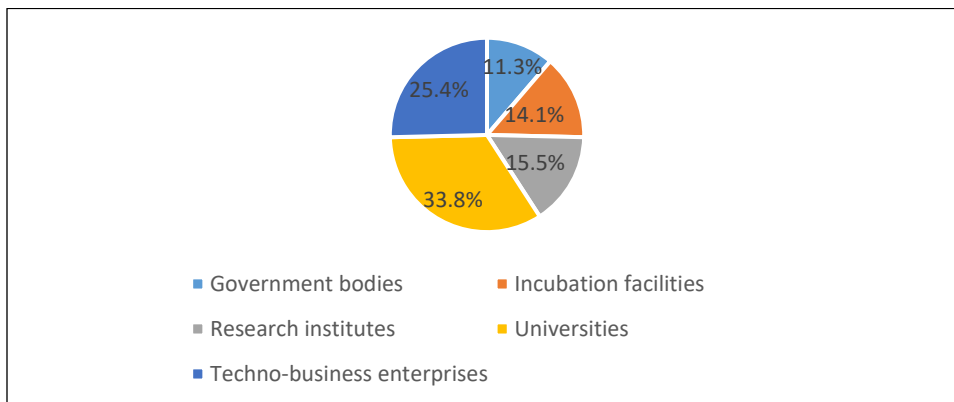
- (i) Data reduction; Involved selecting, clustering, abstracting, and transforming interview transcripts into a manageable and useable format
- (ii) Data display; Data were organized into time-ordered matrices and supplemented with contextual details to facilitate interpretation.
- (iii) Drawing conclusions and verification; Key results were evaluated and, where necessary, reanalyzed to confirm the findings.

A cross-case analysis was conducted using an explanation-building approach (Mihas, 2019; Lester et al., 2020) to deepen our understanding of the similarities and differences among the case firms. This comparative technique helped to clarify the conditions under which various commercialization factors emerged. The cross-case methodology also enhanced the explanatory power and generalizability of the findings beyond single-case contexts, offering broader insights into innovation commercialization practices in techno-business enterprises.

## Results and Discussion

### *Characteristics of participating organizations*

The study encompassed a diverse range of organizations, including techno-business firms (25.4%), universities (33.8%), research institutes (15.5%), incubation centers (14.1%), and government agencies (11.3%). This information is shown in Figure 3.



**Figure 3:** Organizations as a proportion of the total study firms

## Factors affecting the commercialization of technological innovations in Uganda

### *Firm-specific drivers for innovation commercialization*

The firm-specific factors play a pivotal role in the commercialization of innovations, as they directly impact a firm's ability to introduce new products, services, or technologies to the market.



**Figure 4:** Firm-specific factors affecting the commercialization of technological innovations

### *Firms' competences, knowledge, and expertise*

A firm's success depends on its abilities, knowledge, and expertise (Atiase et al., 2020; Kesselring et al., 2023). In a survey, 36.1% of the Ugandan firms identified these factors as crucial for commercializing technological innovation (Figure 4). According to research, a product with advanced technology may not always perform better than a product with less technology, but effective management and marketing. Uganda has a long history of business practices and is known for its unique crafted products (Fashina et al., 2018; World Bank, 2021). Our findings suggest that individuals with strong technical skills and experience in Uganda's knowledge-based economy oversee startups and techno-business firms in the country.

Management and marketing expertise is often overlooked in favor of technical professionals, who prioritize technological advancements over effective communication with target clients. Several studies have found a deficiency in non-technical skills, particularly in fields such as technical product sales and marketing, which hinders the commercialization process in Ugandan enterprises. Firms that employ personnel with diverse backgrounds and expertise are better equipped to address this challenge and develop successful solutions to genuine problems.

### *Investment-related issues and value proposition*

A unique value proposition is crucial for a product's success. This proposition can take the form of enhanced efficiency, productivity, or performance, thereby providing an additional advantage to the user (Abbas et al., 2018; Zhu et al., 2020). According to this study, 34% of firms identified investment-related challenges and value propositions as firm-specific factors affecting the commercialization of innovations in Uganda (Figure 4). Although technology has the potential to solve problems and generate a positive economic impact, it is unlikely to succeed financially if people are unwilling to pay for it. Furthermore, such technologies struggle to gain the trust and support of investors seeking reasonable returns on their investment. Many products in Uganda have failed to gain market share because of entrepreneurs' poor management of business obstacles (World Bank, 2021). This issue is exacerbated when firms do not consider customer feedback during their product development.

### *Firm size and collaborative nature*

Firms must strive for optimal harmony between assets and capabilities to thrive in uncertain and resource-intensive environments (Abbas et al., 2019; Atwine et al., 2023). According to a survey, 15.3% of the studied firms identified company size and collaborative nature as key factors affecting technological innovation commercialization in Uganda (Figure 4). Collaboration enables firms to share resources and information and access new markets and technology, leading to cost savings, increased sales, and improved product value.

Collaboration with organizations in related fields can help techno-business firms avoid direct competition and benefit from their shared expertise. This approach can expedite expansion, reduce costs, and compensate for a lack of internationalization experience by providing necessary information and support. According to Abbas et al. (2019) and Atwine et al. (2023), establishing a strong international presence typically requires collaboration, which helps firms to overcome international expansion challenges.

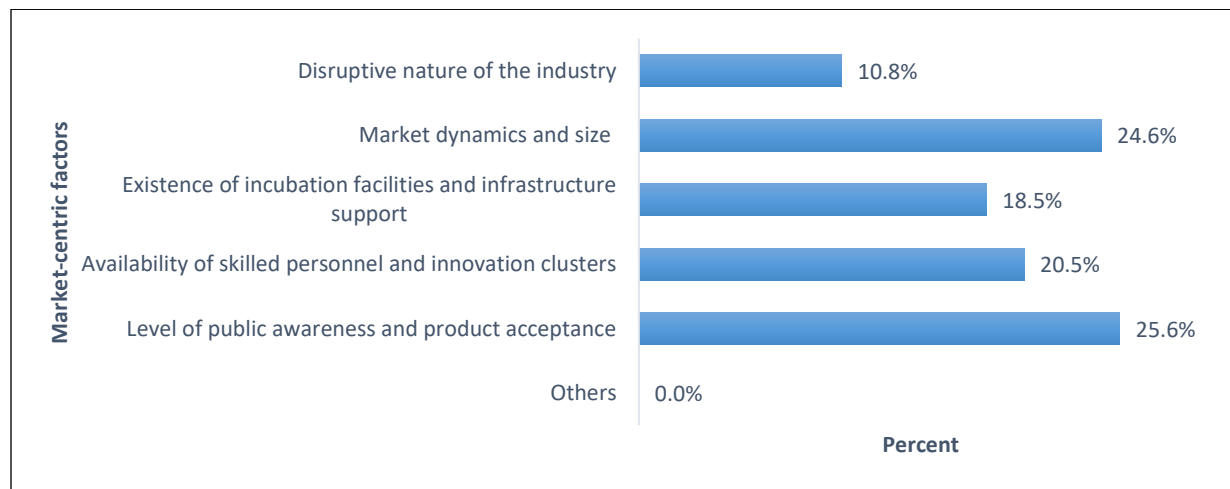
### *Nature of risk within a firm*

The success of entrepreneurship and venture development is not solely dependent on financial elements, market dynamics, and legal frameworks, but also on the cultural and psychological characteristics of individuals within society and a firm (Kim et al., 2019; Saka-Helmhout et al.,

2020). As indicated by the study, 12.5% of firms in Uganda identified the nature of risk within a firm as a firm-specific factor influencing the commercialization of innovations (Figure 4). Firms that are willing to take risks and explore new territories are more likely to succeed in their current or future markets. A firm’s ability to take risks is influenced by various factors, including experience, behavior, personal mentality, social influences, and the overall environment. However, some firms have slow growth and have no plans for expansion.

***Market-centric promoters for innovation commercialization***

The influence of market-centric aspects on the commercialization of inventions is substantial, as they pertain to comprehending and gratifying the demands and preferences of the target market. They are vital for guaranteeing that innovation has a viable market and that it fulfills customer needs effectively.



***Figure 5: Market-centric factors affecting the commercialization of technological innovations***

***Disruptive nature of the industry***

Industry disruptions spurred by technological advancements, shifting customer preferences, or innovative strategies can present challenges and opportunities for businesses attempting to introduce new innovations. In Uganda, 10.8% of firms cited industry disruption as a market-driven factor impacting the commercialization of technological breakthroughs (Figure 5). Firms that disrupt the market often attract many participants, leading to heightened competition from both new market entrants and established competitors who continuously introduce innovative products or services. This increased competition poses a challenge for firms to differentiate between

themselves and achieve market dominance (Crowley & McCann, 2018; Rajapathirana & Hui, 2018). To succeed in this environment, businesses must possess greater distinction, scalability, and marketing acumen, which may also elevate barriers to entry for new ideas.

Rapid technological advancements often disrupt the market, rendering new products or services obsolete. According to Atwine et al. (2023), firms must continuously enhance their offerings to remain competitive. Failure to adapt may result in a loss of market share or obsolescence of firms. In this fast-paced market, firms must be able to quickly identify emerging trends and seize new opportunities to gain a competitive edge. Market disruptions can lead firms to redirect their focus and incorporate innovative business strategies for the successful commercialization of disruptive technologies, which are vital for sustainable growth.

#### *Market dynamics and size*

Uganda's technological innovation market growth is influenced by global demand for modern technology and social transformation. Advanced technology, technical talent, and support infrastructure are opportunities for Uganda. The survey found that 24.6% of firms identified market dynamics and size as market-centric factors. However, Uganda's limited domestic market and lack of widespread technological breakthroughs pose challenges.

According to Fashina et al. (2018) and World Bank (2021), the commercialization of technology in Uganda requires adjustments to infrastructure and consumer behavior. Deliberate efforts are necessary to foster the demand. Domestic procedures and legislation can promote and facilitate the use of new technology, and firms can receive assistance when entering foreign markets. Techno-business firms with substantial market knowledge, technological expertise, and a forward-thinking mindset dominate the Ugandan sector (NPA, 2020; World Bank, 2021). However, these firms often face financial constraints and lack knowledge of global expansion, limiting their potential in domestic markets with limited potential.

#### *The existence of incubation facilities and infrastructure support*

Techno-business firms require access to incubation facilities and infrastructure support (Kwesiga, 2019; Zhu et al., 2020). Of the firms surveyed, 18.5% identified these factors as critical for

commercializing innovation (Figure 5). Incubators, accelerator programs, research groups, and facility parks can provide various types of assistance to firms (Abbas et al., 2018; Kwesiga, 2019). Opportunity exists in offering cost-cutting, expert-driven solutions in countries such as Uganda, which is known for its innovative culture and technical universities. As bio-based firms grow, so does their need for network support.

#### *Availability of skilled personnel and innovation clusters*

Collaboration among techno-business firms, government agencies, and research institutions is crucial for commercializing innovations in Uganda (Abbas et al., 2019; Zhu et al., 2020). Of the firms surveyed, 20.5% identified skilled personnel and innovation clusters as market-driven factors influencing commercialization (Figure 5). To promote firm growth and encourage local inventions, the government should actively embrace new technologies and leverage the limited local markets.

This approach functions as a platform for real-time product showcasing and advertising to clients and stakeholders as well as a testing and refinement tool. Government support for industrial collaboration and international partnerships can further enhance these efforts. The Uganda Cluster Program has demonstrated significant success in promoting technology integration and utilization in the domestic market (Ecuru et al., 2014; Mulumba et al., 2017).

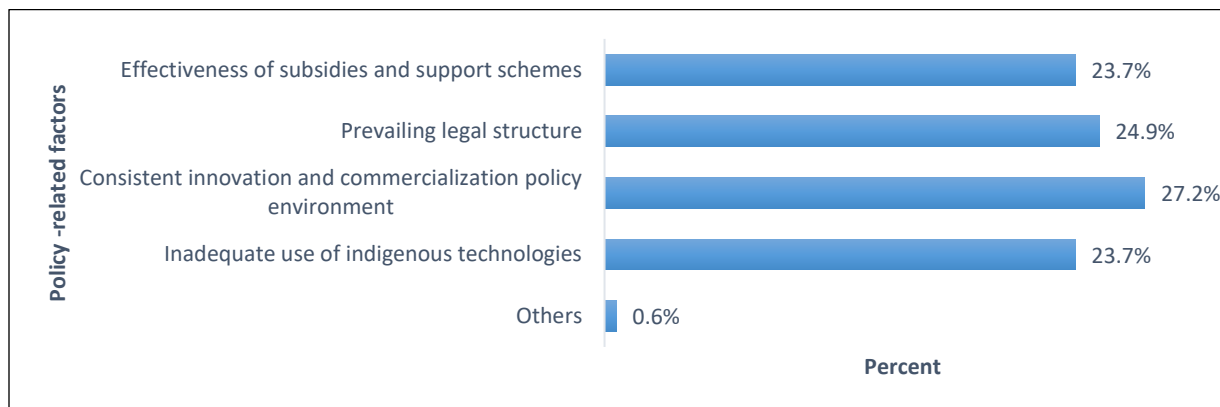
#### *Level of public awareness and product acceptance*

Fashina et al. (2018) and Atwine et al. (2023), stressed that the need for technological advancements in Uganda is primarily driven by social issues. According to the survey, 25.6% of firms view public awareness and product acceptability as crucial market-driven factors affecting innovation commercialization in Uganda (see Figure 5). Addressing the high cost of adoption is essential for overcoming this barrier to innovation development and adoption.

Several researchers have argued that a product's value in the eyes of customers determines its price (Crowley & McCann, 2018; Kim et al., 2019; Avenyo et al., 2021). To justify higher prices for advanced technology, it is essential to emphasize its benefits, which outweigh the increased costs to the user. Ugandan society's focus on enhancing social conditions and well-being makes it crucial to raise public awareness and embrace innovation for successful commercialization.

### ***Policy-related incentives for innovation commercialization***

Policy factors significantly affect the commercialization of inventions. These factors affect the regulatory and business environments in which firms operate and can either speed up or slow down the process of bringing ideas to the market.



**Figure 6:** Policy-related factors affecting the commercialization of technological innovations

#### ***Effectiveness of subsidies and support schemes***

Techno-business firms in Uganda's technology sector lack resources, and small firms require additional funding to transform concepts into significant innovations. Subsidies and support schemes were cited by 23.7% of the firms surveyed as policy-related factors affecting the commercialization of technological advancements in Uganda, aligning with the perspectives of numerous researchers who emphasize finance's significance for businesses as a crucial factor for their continued operation.

Although Uganda's GERD is low compared to similar economies, financial support for techno-business firms is essential. While some firms receive assistance from organizations, such as Uganda Development Bank (UDB), obtaining funding, especially for later-stage firms, remains a significant challenge. Studies by Kim et al. (2019) and Zhu et al. (2020), emphasize the importance of adequate funding at all stages, including R&D and the intermediate phase before the market launch. Improving the lengthy process of providing financial assistance through centralized startup support and single allocation disbursements can address this challenge.

### *Prevailing legal structure*

According to the Global Entrepreneurial Monitor (GEM), Uganda has a favorable legislative environment that supports entrepreneurial activity (GEM, 2022). The country outperforms other countries in providing government support for entrepreneurial initiatives, business creation, and development. However, 24.9% of the surveyed firms identified the current legislative structure as a policy-related issue hindering the commercialization of innovations in Uganda. Although the regulatory environment is generally stable and supportive of firms, there is room for improvement in the technological licensing process, which is complicated and involves numerous procedures and standards (Fosci et al., 2019; CHANE & Atwal, 2023). Enhancing Uganda's legal framework would enable firms to accelerate the commercialization of technological innovation.

### *Consistent innovation and commercialization policy environment*

A well-balanced regulatory framework and government assistance programs are essential for promoting innovation adoption (UNCTAD, 2020; Aktar et al., 2021). In Uganda, 27.2% of the firms identified a stable innovation and commercialization policy environment as a key policy factor affecting innovation commercialization (Figure 6). Although Uganda has made notable progress in becoming a significant market player through effective policies and processes that foster growth, concerns have been raised regarding the lack of a comprehensive and consistent policy approach. Appropriate policies implemented by the government are crucial for creating favorable conditions that drive technological advancement (Uyarra et al., 2020; Aktar et al., 2021).

### *Inadequate use of indigenous technologies*

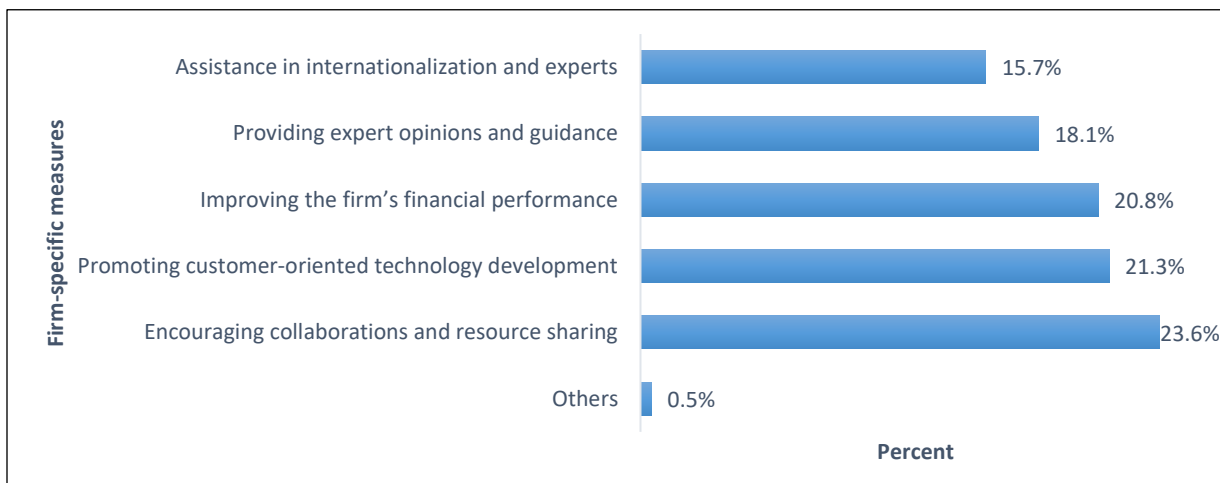
This study analyzed the role of indigenous technology in promoting sustainable economic growth, preserving cultural diversity, and improving the livelihoods of local communities. It was found that 23.7% of the firms surveyed identified a lack of utilization of indigenous technology as a policy-related issue hindering innovation commercialization in Uganda. Indigenous technologies can play a significant role in commercializing inventions and contributing to economic growth, social progress, and cultural preservation in the country (Ongâ & Abbey, 2019; NPA, 2020). Uganda's rich cultural diversity and traditional knowledge systems provide a promising platform for the commercialization of indigenous innovations.

Traditional farming methods such as agroforestry, crop rotation, and organic farming offer sustainable alternatives to conventional techniques that benefit the environment. In addition, commercializing indigenous medical knowledge can preserve traditional therapeutic practices and provide economic opportunities (Ongâ and Abbey, 2019). Similarly, commercializing indigenous creative traditions can help craftsmen support themselves, boost cultural tourism, and preserve their cultural heritage.

**Recommended firm-specific, market-centric, and policy-related measures**

***Measures for overcoming firm-specific barriers***

Commercializing innovations effectively hinges on firm-specific strategies that capitalize on a firm's unique assets and capabilities to enhance its chances of success and to provide a competitive edge in the market.



**Figure 7:** Firm-specific measures to overcome barriers to commercialization of technological innovations

*Assistance in internationalization and experts:* Avenyo et al. (2021) emphasize the significance of a firm's culture of innovation and entrepreneurship, skilled and motivated employees, and effective management procedures for successful product commercialization. The study found that 15.7% of the Ugandan firms cited internationalization support as a means of overcoming internal obstacles. To improve commercialization, firms should invest in employee training and development and foster an innovative environment. A well-defined commercialization plan is

necessary to overcome firm-specific constraints, including a thorough market study, identification of target customers, pricing strategies, marketing plans, and distribution networks.

*Providing expert opinions and guidance:* Market trials conducted professionally before fully launching a product can help to identify and resolve issues (Demirel & Kesidou, 2019; Kreiterling, 2023). Of the Ugandan firms surveyed, 18.1% cited receiving expert opinions and assistance to overcome obstacles during commercialization (Figure 7). This approach allows firms to gauge market demand, obtain inputs from early adopters, improve their products/services, and adjust. This provides valuable insights for refining the commercialization plan and minimizing the scaling-up risks. Firms should regularly assess their commercialization efforts, be adaptable, and monitor market trends, competitors, and consumer feedback to identify emerging obstacles and adjust their strategies accordingly. Being responsive and agile can help firms manage barriers and maximize the commercialization potential of their innovations.

*Improving a firm's financial performance:* Access to ample financial resources is essential for technology-driven firms to overcome obstacles. According to Omri (2020), firms should explore alternative funding sources such as venture capital, investors, government subsidies, and crowdsourcing. In Uganda, 20.8% of firms identified better financial performance as a means of overcoming firm-specific obstacles in the commercialization of technological innovations. Adequate capital allows firms to invest in R&D, scale-up manufacturing, effectively market, and disseminate innovation. One of the major challenges in commercializing breakthroughs is the risk of IP infringement, which requires firms to prioritize IP protection through patents, trademarks, copyrights, and trade secrets. Strong IP protection provides legal protection and enhances a firm's ability to profit from inventions.

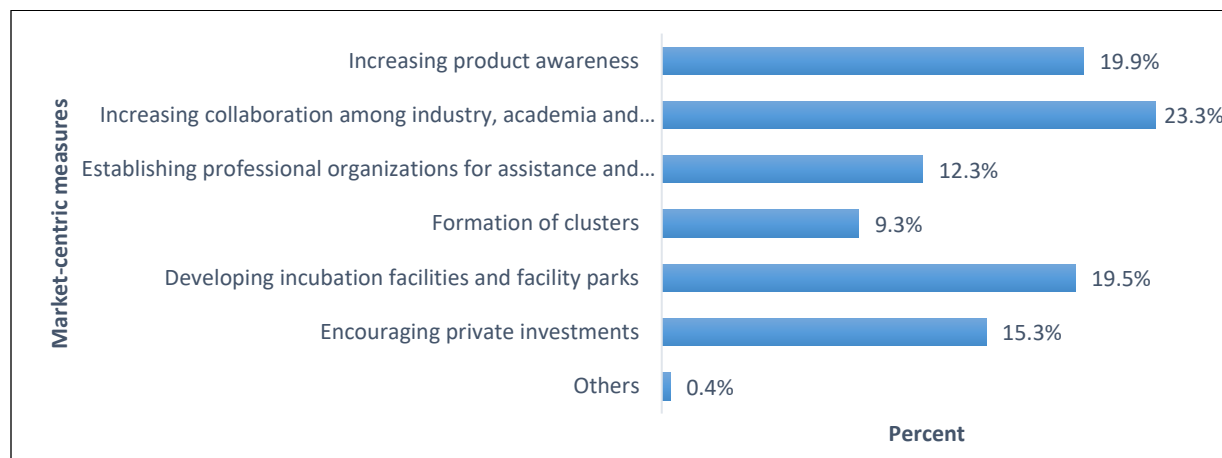
*Promoting customer-oriented technology development:* Firms must understand their clients' requirements, preferences, and areas of discomfort to achieve commercialization success (Hussen & Çokgezen, 2022; Ojubanire et al., 2023). A survey conducted as part of this study revealed that 21.3% of the firms surveyed identified customer-oriented technology development as a means of overcoming firm-specific obstacles to the commercialization of innovations in Uganda. Firms should conduct market research, establish channels for obtaining consumer feedback, and engage with potential customers during the product development process to ensure customer-centric

development. By aligning their products with client needs, firms can improve their prospects for commercialization.

*Encouraging collaboration and resource sharing:* According to Abbas et al. (2019) and Zhu et al. (2020), partnering with strategic businesses can help overcome commercialization hurdles. Building partnerships and sharing resources are means to surmount firm-specific obstacles to commercializing innovations in Uganda, as 23.6% of the participating firms identified (Figure 7). Collaboration enables access to production, distribution, and marketing expertise. Enhancing marketing capabilities for innovative products by combining the specialized knowledge of multiple businesses is another benefit. Licensing agreements can alleviate constraints related to manufacturing, distribution, or market access, as firms can use established distribution channels and partners' proven market presence.

***Measures for overcoming market-centric challenges***

Market-focused strategies are crucial for achieving commercial success by overcoming obstacles and addressing the needs and preferences of a target market. These strategies focus on the metrics that help firms overcome specific barriers.



**Figure 8:** Market-centric measures to overcome barriers to commercialization of technological innovations

*Increasing product awareness:* According to Muriisa and Rwabyoma (2019) and Kruachottikul et al. (2023), enhancing product awareness is crucial for overcoming market-centric challenges in commercializing innovations. Research indicates that 19.9% of the firms in Uganda cite this as a solution (Figure 8). To effectively innovate, firms must emphasize their benefits, characteristics,

and distinctions while using digital marketing channels and social media platforms to reach a broader audience.

*Increasing collaboration among industry, academia, and government:* Firms must form strategic partnerships with industry, academia, and the government to benefit from market expertise, distribution networks, and client bases (Abbas et al., 2019; Zhu et al., 2020). The survey results indicate that 23.3% of the firms in the study view increased collaboration as a means of overcoming market-centric barriers to the commercialization of technological innovations in Uganda. Collaboration with key stakeholders can provide access to resources, networks, and knowledge to help overcome obstacles to market entry.

*Establishing professional organizations for assistance and guidance:* Demirel and Kesidou (2019) noted that professional organizations help firms comply with industry regulations and standards. In this study, 12.3% of Ugandan firms formed professional groups for support and advice to overcome market barriers to innovation commercialization. Collaboration with regulatory agencies early in development is crucial for ensuring safety, quality, and legal compliance. Market research is necessary to identify client needs, preferences, and obstacles, and gathering feedback from potential consumers helps validate the demand for inventions.

*Formation of clusters:* According to Barasa et al. (2017) and Kim et al. (2019), clusters allow firms to adapt to the changing market requirements and trends. Among the 9.3% of surveyed firms that identified clustering as a solution to market-related challenges, improved customer feedback, market trends, and technological advancements are crucial for competitiveness. Firms must understand the competitive landscape, including existing solutions, pricing structures, and market positioning, and develop a compelling value proposition that differentiates them from their competitors.

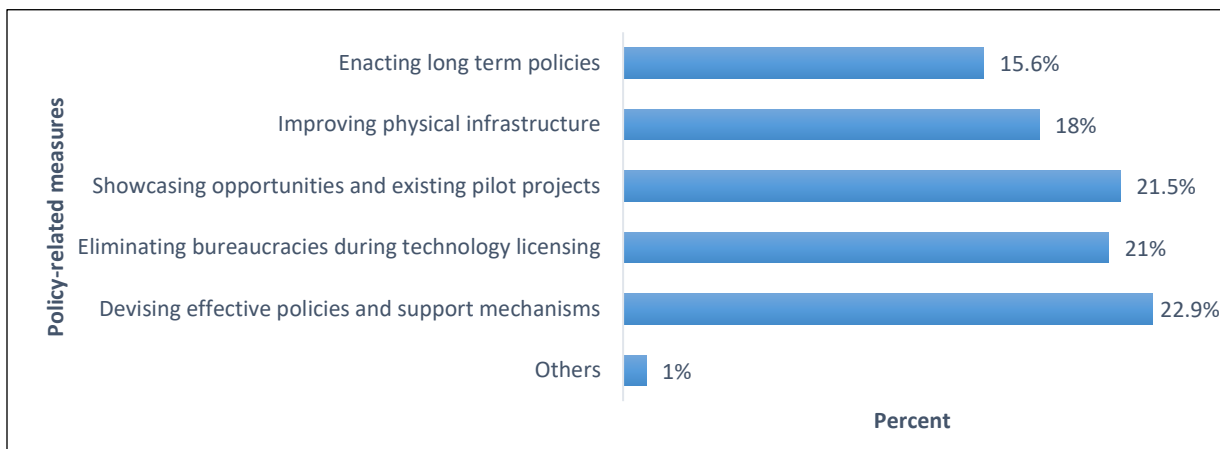
*Developing incubation facilities and facility parks:* Incubation centers and facility parks provide an environment for businesses to launch pilot programs and test products, enabling them to assess market response, collect data on product performance, and gain insights into customer feedback and market demand (Kwesiga, 2019). According to this study, 19.5% of firms identified the establishment of these facilities as a means of overcoming market-centric barriers to the

commercialization of innovations. These facilities support product iteration and refinement, allowing businesses to make the necessary adjustments before expanding. To ensure that innovations meet expanding market needs without compromising quality or performance, businesses must design their innovations with scalability.

*Encouraging private investments:* According to Bakhtiar et al. (2020) and Kruachottikul et al. (2023), private investments are crucial for firms during the commercialization phase. In Uganda, 15.3% of the firms identified private investment promotion as a means of overcoming market-centric obstacles (Figure 8). Firms can consider various funding options such as venture capitalists, angel investors, government grants, and crowdfunding platforms. A strong financial position enables firms to implement scaling, marketing, and market entry strategies. The availability of private investments can be critical in helping firms overcome market-centric challenges and successfully commercialize their innovations.

***Measures for overcoming policy-related constraints***

These measures are essential for removing policy-related barriers that hinder the commercialization of inventions. They help governments and regulatory organizations address specific issues by creating a supportive environment for businesses to introduce new products, services, or technologies into the market.



**Figure 9:** Policy-related measures to overcome barriers to commercialization of technological innovations

*Enacting long-term policies:* Policymakers must evaluate and modify their strategies regularly to effectively drive innovation and commercialization. This study noted that 15.6% of the Ugandan

firms surveyed identified streamlining bureaucratic procedures, reducing regulatory burdens, and fostering a supportive business environment as crucial to overcoming policy-related barriers to innovative commercialization (Figure 9). It may be necessary to implement new incentives and financing structures to support innovative businesses and adjust existing policies (Uyarra et al., 2020; Aktar et al., 2021).

*Improving physical infrastructure:* Physical infrastructure is a controlled environment in which firms can test and confirm the effectiveness of new products, services, and business models (Kwesiga, 2019; Atiase et al., 2020). The study revealed that 18% of the surveyed firms listed physical infrastructure improvement as a strategy to overcome policy-related obstacles in the commercialization of innovations in Uganda (Figure 9). Collaborating with governments and regulatory agencies allows companies to provide the necessary physical infrastructure, enabling them to navigate complex regulations and demonstrating the feasibility of their ideas without full compliance.

*Showcasing opportunities and existing pilot projects:* Governments should invest in education and skill development programmes to cultivate a workforce receptive to new ideas. Research indicates that 21.5% of firms believe in showcasing potential prospects, and current pilot projects can help overcome policy-related barriers that impede the commercialization of innovations in Uganda (Figure 9). Policymakers should promote vocational training, STEM education, and entrepreneurship education to develop a skilled workforce that can support firms' innovation and commercialization initiatives (Kwesiga, 2019; Kolade et al., 2021).

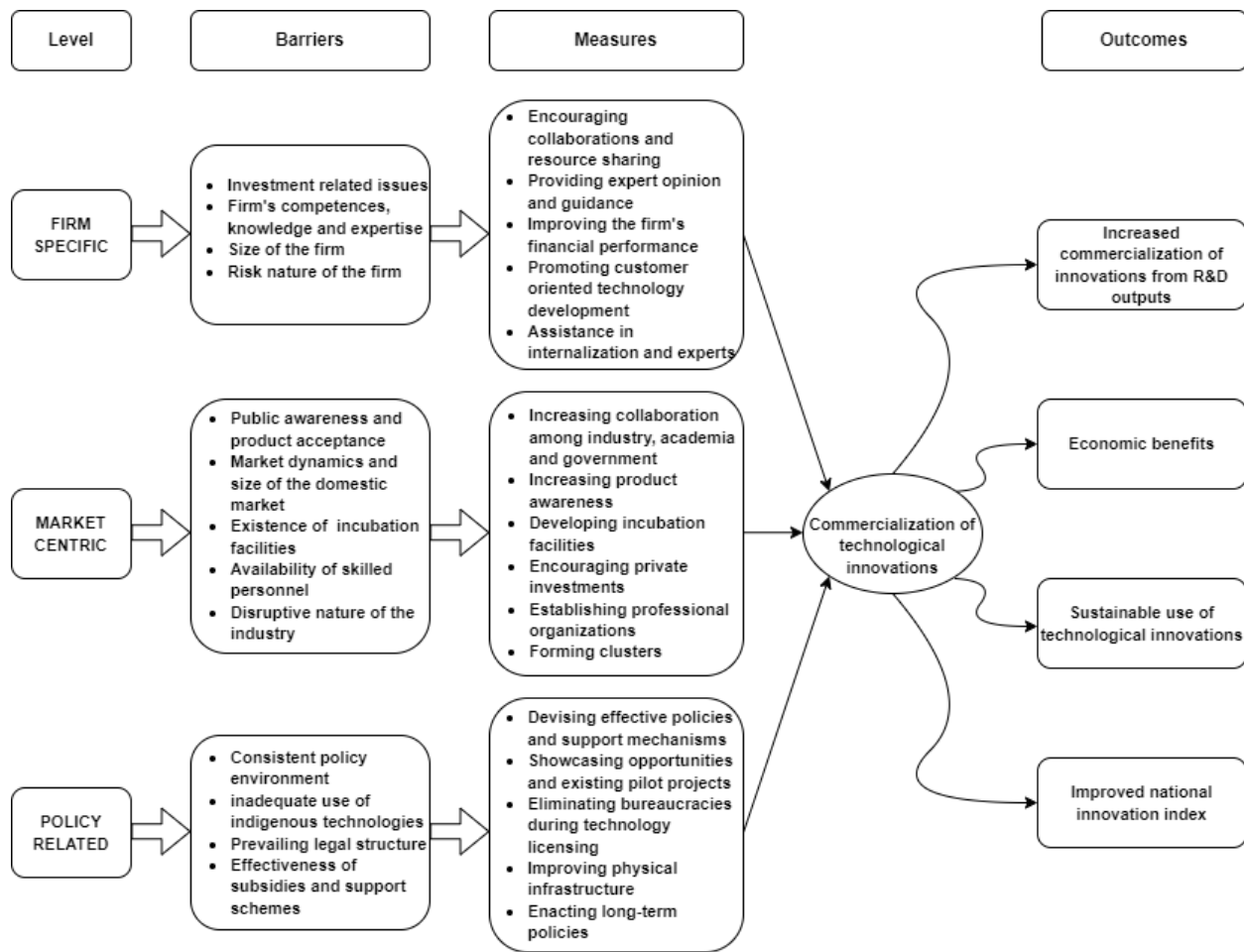
*Eliminating bureaucracies during technology licensing:* According to Abbas et al. (2018) and Kesselring et al. (2023), developing predictable and adaptable policy frameworks is crucial to streamlining technology licensing and reducing bureaucratic obstacles. Of the surveyed firms in Uganda, 21% identified the elimination of bureaucracy as key to overcoming policy-related challenges in commercializing innovations (see Figure 9). To address this issue, the government should establish clear, transparent regulations, and predictable approval processes. Additionally, regulatory agencies must be prepared to modify legislation as technology advances, to avoid stifling innovation.

*Devising effective policies and support mechanisms:* Developing comprehensive funding rules is crucial for the successful commercialization of innovations (Uyarra et al., 2020; Aktar et al., 2021). In Uganda, 22.9% of the surveyed firms viewed the development of effective policies and support mechanisms as essential for overcoming policy-related challenges in commercializing innovations (Figure 9). To address this issue, the government should establish funding programs and venture capital initiatives that target creative startups and medium-sized businesses. These programs can provide grants, tax incentives, low-interest loans, and investments in startups to support innovation-driven businesses financially.

### **Framework proposition**

According to Gbadegeshin (2018) and Bakhtiar et al. (2020), commercializing technology can be challenging. A comprehensive framework is necessary for successful commercialization at the firm, market, and policy-related levels, as demonstrated by the research conducted in this study. Focusing on one aspect alone will not lead to successful marketing, because it depends on several key factors.

Firms must acquire essential knowledge, skills, and resources to commercialize technological innovations, particularly startups, spinoffs, and techno-business firms. A suitable infrastructure is crucial, and firms can use facility parks, incubation facilities, and professional associations to compensate for their limited resources. Securing funding is a crucial aspect of the development process, and firms can attract investor interest by acquiring technical skills and a well-defined development and commercialization plan (Shakeel et al., 2017; Gbadegeshin, 2018). Sourcing funding from the government or the private sector is possible (Avenyo et al., 2021). Collaboration among stakeholders involved in the process is necessary to promote public understanding and recognize the economic benefits of technology (Gbadegeshin, 2018).



**Figure 100:** Framework for commercialization of technological innovations (Source: Authors)

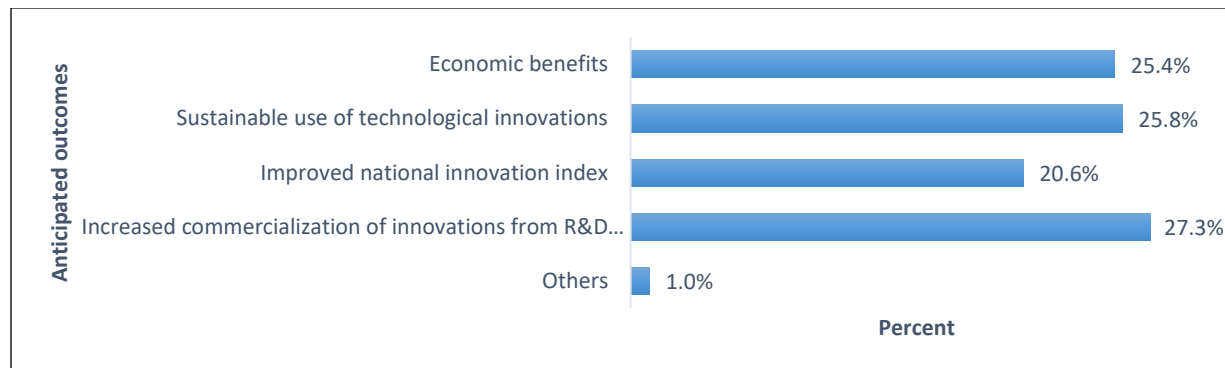
Additionally, external factors such as legal frameworks, government subsidies, and support mechanisms play a critical role in the successful commercialization of technological advancements (Figure 10). However, the impact and scope of these interventions can vary based on factors, such as firm size, available resources, expertise level, corporate reputation, market understanding, and national and international networks. Eliminating these obstacles can result in beneficial outcomes such as increased market acceptability, enhanced competitive advantage, broader market reach, and contributions to economic growth and societal well-being. By doing so, firms can gain favorable market influence, establish strong market positions, and foster long-term growth in their ideas.

## Indicators for evaluating innovation commercialization success or progress at the firm, market, and policy levels

The proposed innovation commercialization framework was validated using the following criteria:

- a) Coherence analysis: This involved ensuring that innovation commercialization concepts are well defined, and the relationships between them are clear and logical.
- b) Exhaustiveness analysis: This involved verifying that the innovation commercialization framework covers all relevant aspects of the problem (CVD).
- c) Expert feedback: This involved seeking input from experts in the field of innovation commercialization to assess the framework's validity and relevancy.

The following indicators for evaluating success or progress at the firm, market, and policy levels were highlighted by innovation commercialization experts in line with the proposed commercialization framework.



**Figure 11:** Anticipated outcomes of overcoming firm-specific, market-centric, and policy-related barriers to commercialization of innovations

*Economic benefits:* According to Breitenbach and Malan (2020) and Perry (2020), monetizing successful ideas can stimulate economic growth and development. The survey found that 25.4% of the firms believed that overcoming barriers related to firm-, market-, and policy-related issues could lead to economic benefits (Figure 11). This can be achieved by introducing new goods and services, creating new business opportunities, and driving investment and employment across industries. The successful commercialization of innovations can also attract additional investment and financing opportunities. Proven track records of profit generation make firms more attractive to investors and to funding sources.

*Sustainable use of technological innovations:* Enhancing accessibility is crucial for commercializing inventions that address social issues, foster sustainability, and improve the quality of life (Bowman, 2019; Atiase et al., 2020). The survey found that 25.8% of firms believed that overcoming firm-specific, market-centric, and policy-related barriers to innovation in Uganda would result in sustainable adoption of technological advancements (Figure 11). Innovations in renewable energy, healthcare, transportation, and resource management can contribute to a more sustainable future, promote public welfare, and reduce environmental impact.

*Improved national innovation index:* Addressing barriers such as regulatory hurdles, safeguarding intellectual property, and financial limitations can lead to technological advancements and a higher national innovation index (Dutta et al., 2022; Alqararah, 2023). The findings indicate that 20.6% of the surveyed firms believe that eliminating obstacles related to the firm, market, and policy can improve the national innovation index in Uganda (Figure 11). The government should implement clear, supportive policies to encourage companies to invest in R&D and to promote collaboration between universities and industry. Successfully commercializing innovations can help firms differentiate themselves from their competitors, attract new customers, and expand their market shares.

*Increased commercialization of innovations from R&D outputs:* According to Zhu et al. (2020), addressing organizational challenges can unlock the potential of innovations and enhance the commercialization of R&D outputs. In Uganda, 27.3% of the firms identified commercialization as an area that could benefit from overcoming firm-, market-, and policy-related obstacles (Figure 11). Successful commercialization can lead to the introduction of new products, services, and processes. Collaboration and knowledge exchange among stakeholders such as academics, industry, government, and investors can provide platforms for cooperation, exchange best practices, and promote idea exchange, leading to more effective commercialization initiatives.

## **Conclusion**

Innovation commercialization is complex and context-dependent. Successful approaches require a deep understanding of customer demand and the national innovation ecosystem. Techno-business models must be tailored to local realities, including firm size, technological regimes, and socioeconomic conditions. Technopreneurs must refine their models to close the gap between

providers and end-users. Strategies should cover all phases, including financing, development, diffusion, and legitimation, while addressing barriers and optimizing local impact. A successful commercialization strategy must address knowledge gaps, especially those relating to regulatory barriers such as restrictive intellectual property laws. Policies should reflect an in-depth understanding of the factors that attract or deter private sector investment in innovation commercialization endeavours, particularly in the context of Uganda's economic realities. Therefore, there is a pressing need to identify effective and sustainable financing models for innovation that combine public, private, and international resources.

### ***Theoretical implications***

The process of commercializing innovation may not be best served by a universal approach, as the size of the firm and technological regimes are important considerations (Min et al., 2020; Loganathan & Subrahmanya, 2022). The challenges of commercializing science, including uncertainty and capital requirements, underscore the need for customized strategies and frameworks that can generate both economic and social value (Bakhtiar et al., 2020). The review of technology financing and commercialization processes, including the significance of crossing the chasm with mass markets, suggests that a deep understanding of customer groups and the national innovation system is critical for successful commercialization (Gong et al., 2021). The high-risk and high-cost nature of the critical phase of commercialization in high-tech markets highlights the need for better management and the significant impact of commercialization decisions on market success or failure (Kruachottikul et al., 2023).

The slow rate of technological advancement in Organisation for Economic Cooperation and Development (OECD) countries, attributed to social and economic hurdles (OECD, 2021), suggests that similar obstacles may exist in Uganda. Therefore, it is crucial to concentrate on both supply and demand to promote adoption and diffusion (Mallinson, 2021). Business models play a crucial role in facilitating the adoption and dissemination of technological advancements. Therefore, innovation providers must refine their business models to bridge the gap between providers and end-users (Noeh et al., 2022). The role of e-business entrepreneurs in promoting the adoption of cloud computing services through social cognitive theory underscores the significance of social learning and individual belief systems in terms of technology adoption (Chen, 2024). The processes of innovation legitimation, which serve as an essential step in the broader adoption of

groundbreaking innovations, highlight the role of system builders and the need to align organizing visions within the technological innovation ecosystem (Yim et al., 2024).

The theoretical implications for Uganda necessitate a comprehensive approach to commercialization that considers the unique technological regimes, firm sizes, and socio-economic conditions within the country. Strategies should be customized to effectively manage the innovation process, ranging from financing and development to diffusion and legitimation, with a focus on overcoming socioeconomic barriers and optimizing business models for the local context. Understanding the role of system builders and the significance of aligning visions within the innovation system can further facilitate the commercialization of technological innovations in Uganda.

### ***Policy implications***

There is a need to enhance regulatory frameworks in order to create a conducive policy environment in Uganda. A streamlined, transparent, and adaptive regulatory environment is essential for supporting innovation. Licensing processes should be simplified to reduce bureaucratic overheads and increase efficiency. Policies should include the creation of a dedicated innovation commercialization fund to provide financial and advisory support to early-stage enterprises. Such initiatives should offer grants, tax breaks, low-interest loans, and equity investments to innovation-driven businesses. Policymakers must align STI policies across government MDAs, enhance policy coherence, and strengthen their implementation capacities. Long-term success depends on the transition from subsistence-based output to high-value industrialized production chains. Policymakers and stakeholders must ensure the effective enforcement of policies to enhance the STI ecosystem and improve legal and regulatory frameworks for commercializing technological innovations (Min et al., 2020; Kruachottikul et al., 2023).

The importance of R&D is emphasized in the context of technological innovation. Nevertheless, findings from the industrial sectors indicate that post-R&D phases, such as technology transfer and diffusion, are crucial for economic growth and should be supported by government policies (Mallinson, 2021). Moreover, the success of technology commercialization in small and medium-sized enterprises (SMEs) is significantly influenced by government support, appropriability,

innovative capabilities, and investment in external R&D (Chen, 2024; Kurekova et al., 2023). This underscores the government's role as an enabler of commercialization through financial and policy support.

The successful commercialization of technological advancements in Uganda hinges on the establishment of comprehensive policies covering various aspects. These policies must provide government support during the research, development, and post-research and development phases, while simultaneously considering the social and cultural effects of innovation. Furthermore, it is crucial to extend the targeted assistance to small and medium-sized enterprises. Policymakers must endeavor to create an environment that encourages technological progress, while preserving cultural traditions and promoting economic growth.

### ***Ideas for future research***

Future research on the commercialization of technological advancements in Uganda would advantageously adopt a multifaceted approach that addresses the identified hindrances and builds upon the successful traits of the commercialization processes. One potential area of focus could be the influence of government support in stimulating the development of high-tech innovations and creative firms, as well as the efficiency of national initiatives in nurturing a startup ecosystem (Gbadegeshin et al., 2022; Ojubanire et al., 2023). Another promising avenue for research is the assessment of the impact of digital entrepreneurship on the commercialization process. Studies have scrutinized the influence of digital enterprise models, entrepreneurial procedures, and ecosystems on the success of technological innovation in Uganda (Baig et al., 2022).

Investigating the development of an efficient innovation funding mechanism, especially in challenging situations such as martial law, could provide valuable insights into how to support innovation during economic downturns (Zaburanna & Yarmolenko, 2022). Moreover, research could examine the influence of globalization on innovative entrepreneurship and develop a legal framework that includes a clear definition of innovation, financial incentives, and qualified personnel training through innovation and technological centers (Ojubanire et al., 2023). Furthermore, this study emphasizes the significant role of the government in ensuring access to digital technologies and financial support for innovative initiatives as well as the effects of digital technologies on the transformation of entrepreneurial activities (Baig et al., 2022).

Ultimately, the role of university technological business platforms in promoting regional economic growth and facilitating cooperation between technology commercialization stakeholders can provide valuable insights for enhancing the stimulation of technological entrepreneurship (Kolade et al., 2021). The effects of innovation and technology on social entrepreneurship offer useful lessons for Uganda, particularly regarding government policies, funding resources, and support networks (Hogan et al., 2022; Zaburanna & Yarmolenko, 2022; Kurekova et al., 2023). These studies offer a comprehensive understanding of the factors that contribute to successful commercialization and economic expansion in Uganda and the surrounding region.

## Declarations

**Data availability statement:** The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

**Disclosure statement:** The authors report there are no competing interests to declare.

**Authors' contributions:** All authors contributed to the writing of the manuscript and have read and approved the final manuscript.

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