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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

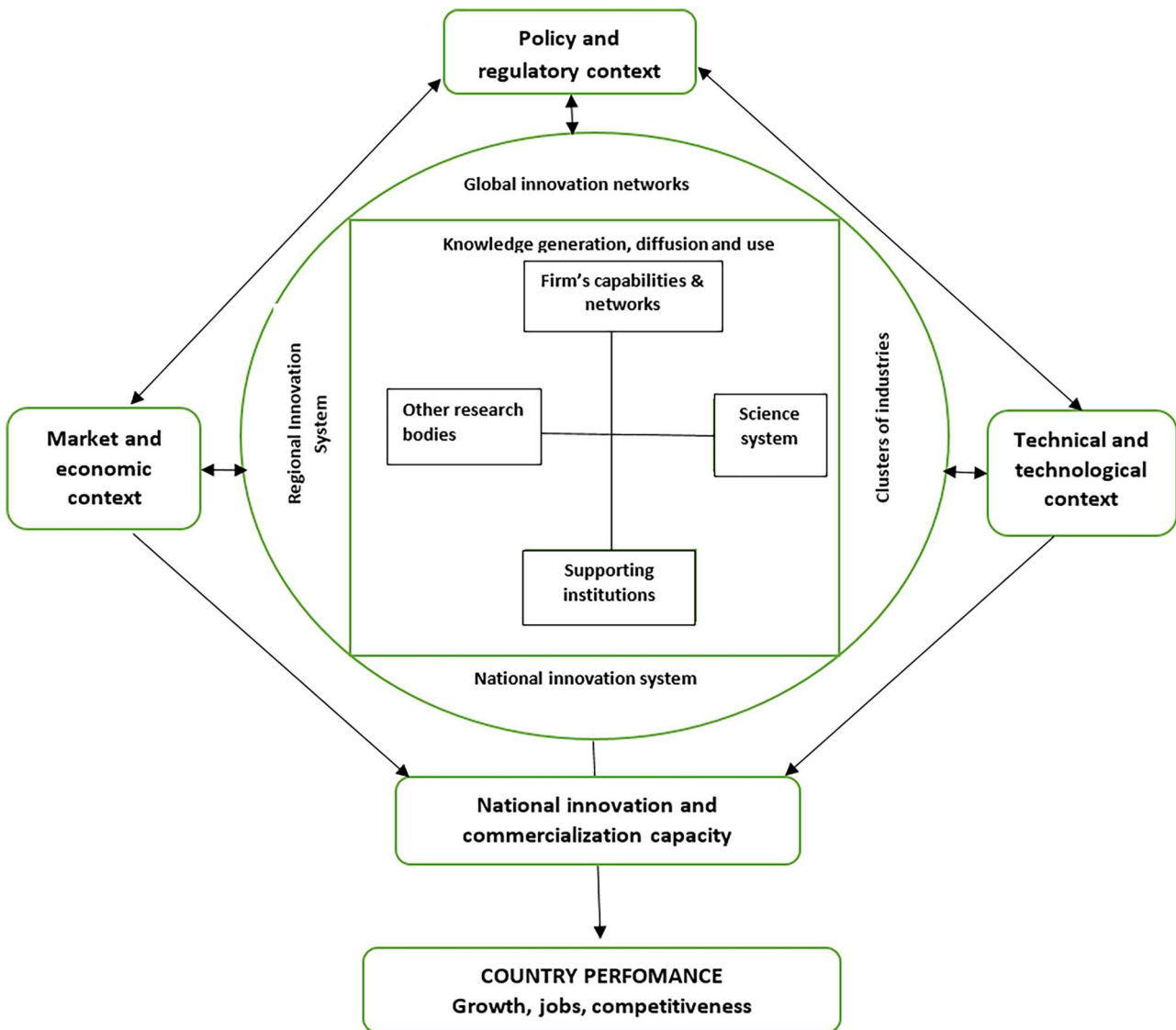
from 0.37% in 2002. Most of this R&D expenditure was conducted by the public sector and was funded by overseas donors. The private sector’s involvement in R&D is limited, with most private sector enterprises conducting R&D as foreign direct investment (FDI) (UNCST 2016a, 2016b).

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

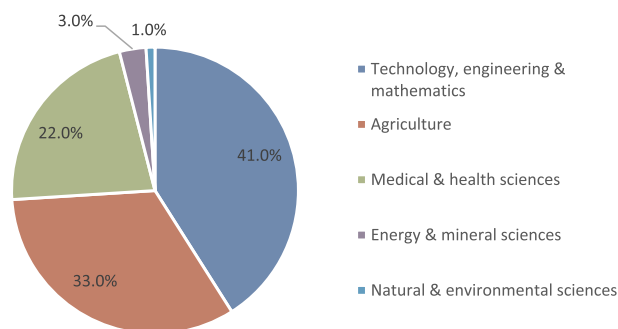
Case studies of different R&D grant interventions were employed to illustrate the magnitude and significance of the outcomes achieved through R&D grants and investments. These case studies were analyzed on a case-by-case basis (Plotz 2020) using a structured framework that included context and reasoning, 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, Ďurčková, 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, Ďurčková, 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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