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Sustainable technology development during intellectual property rights commercialisation by university startups

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Abstract

Purpose – The purpse of this study is to examine sustainable technology development (STD) during the "Valley of Death" phase encountered by university startups undertaking intellectual property rights (IPR) commercialisation.

Design/methodology/approach – A comprehensive literature review was conducted after searching for relevant documents across multiple databases. Semi-structured interviews with university startup founders were also conducted as part of a qualitative case study.

Findings – This study resulted in two significant findings. First, the Valley of Death has been redefined in the specific context of IPR commercialisation by university startups. Second, the sustainable technology development framework (STDF) has been conceptualised to enhance the success rate of IPR commercialisation by university startups. The authors also identified three essential components of STD in the context of university startups: market development, technical efficiency and business sustainability.

Research limitations/implications – This exploratory research involved a thorough literature analysis. Given that only one qualitative case study was conducted, data saturation was not achieved. Further empirical research is needed to validate the conceptualised STDF.

Practical implications – The validated STDF will be a useful tool for enhancing the success of IPR commercialisation by university startups.

Originality/value – While others have focused on innovating business models, this study focused on an underexplored area: the sustainability of technology development during the commercialisation of IPR by university startups during the Valley of Death phase.

Keywords Valley of Death, Technology development, University spinoffs, University startups, R&D commercialisation, Intellectual property rights

Paper type General review

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1. Introduction

The commercialisation of intellectual property rights (IPR) by university startups or spinoffs has garnered significant attention in recent years (Mathisen and Rasmussen, 2019; Vutsova and Arabadzhieva, 2021). The terms “university startups” and “university spinoffs” refer to recently established companies that are formed with the specific purpose of commercialising technologies developed within university laboratories (Harmon *et al.*, 1997; Vohora *et al.*, 2004; Hogan and Zhou, 2010). University startups acquire the IPR associated with technologies developed within university laboratories and collaborate with entrepreneurs to launch ventures (Siegel and Phan, 2005; Hogan and Zhou, 2010). Nevertheless, when university startups are used as vehicles for commercialisation, they face a significant challenge: a notable rate of failure. The failure rate of startups is generally quite high, ranging from 70% to 80% (Nobel, 2011), and some reports have even suggested that the failure rate is 90% (Blank, 2013; Bednár and Tarišková, 2017). During IPR commercialisation, startups can reach challenging “critical junctures” that encompass, for example, opportunity recognition, entrepreneurial commitment, venture credibility and venture sustainability. In addition, factors such as limited resources, internal capability deficiencies and poor networking can accumulate to create impediments in the value creation process (Vohora *et al.*, 2004). The challenges and barriers that university startups encounter during their development can be analysed at the micro (individual academic), meso (university) and macro levels (regional and national contexts) (Hossinger *et al.*, 2020).

The failure of startups can be attributed to multiple factors from the science commercialisation and management perspectives, and this contributes to the complexity of IPR commercialisation. A key cause of failure is the inability of startups to continuously develop their technology in response to market demands and overcome the “Valley of Death”, a term used to describe the transition (or gap) between the basic research and development (R&D) and commercialisation phases (Branscomb and Auerswald, 2002; Markham, 2002; Evans, 2002). In other words, the failure of a startup is inevitable when its founders cannot translate new inventions into viable products or services for the market (Osterwalder and Pigneur, 2010; Ries, 2011; Blank, 2013). Within the context of this study, “new inventions” refers to IPR developed by universities and licensed to university startups. This demonstrates that IPR developed in university laboratories need further refinement and development before they can be commercialised (Barr *et al.*, 2009). In addition, from the product development perspective, lack of technology development to create market-oriented end products is a leading cause of failure for many inventions (Osawa and Miyazaki, 2006).

Because of the limited research on how to ensure the sustainability of technology development during IPR commercialisation within university startups, we have developed a framework called the sustainable technological development framework (STDF) to enhance the success rate of IPR commercialisation by university startups. Additionally, previous studies on the Valley of Death phenomenon have predominantly examined it within either the university or firm contexts in isolation (Dean *et al.*, 2022). Therefore, in this study, we have comprehensively investigated the Valley of Death phenomenon in both the university and firm contexts by exploring the commercialisation of IPR generated within universities (university context) through the utilisation of university startups (firm context). We have also proposed a new definition of the Valley of Death that is specific to the commercialisation of IPR by university startups. In the broader context of innovation and technology transfer, the findings of this study highlight (1) the issues and challenges faced by university startups that license intangible IPR containing technological solutions from universities and (2) how university startups can enhance the success rate of IPR commercialisation by addressing technical, market and business sustainability aspects while navigating the Valley of Death.

2. Research methodology

We performed an extensive literature search and analysis, following the steps outlined by Hart (2001), which included (1) locating information references, (2) identifying pertinent articles and (3) finding item reviews. For the literature search, we used key terms that included "intellectual property rights" OR "technology", "commercialisation" OR "commercialization", "R&D commerciali?ation", "university spin-off", "university startup", "startups" and "Valley of Death". The key terms were used to search multiple databases, such as Google, Google Scholar, Web of Science, Scopus, Science Direct, Springer, Taylor & Francis, SAGE journals and Emerald Insight. To streamline each search, we conducted preliminary reading to narrow down the pool of research findings. In total, we gathered and analysed 458 documents from diverse sources that encompassed reports, patents, theses, agency publications and journal articles. These chosen materials were comprehensively reviewed to assess their suitability in relation to the objectives of this study, and 121 documents were found relevant to the study.

Based on the content and relevance of these documents, we conducted a qualitative content analysis of the literature to identify themes pertaining to the challenges and issues of sustainable technology development (STD) from the perspectives of technical efficiency, market development and business sustainability. To validate these themes in terms of the findings of the existing literature, we used content and comparative analyses, following the approach recommended by Miles *et al.* (2014).

Additionally, we enhanced our literature analysis by incorporating insights from a case study that was part of our preliminary qualitative investigation. For this, we conducted semi-structured interviews with two participants: an academic researcher and an entrepreneur associated with a university startup established in 2016 that had obtained a patent for the production of carbon quantum dots from a university that we refer to as University Alpha (UA) in this paper. Throughout this paper, we refer to this startup as "BetaAgritech". The interviews lasted for 40–90 min. We meticulously recorded and transcribed the interviews with the assistance of Sonix.ai. Subsequently, we shared the transcribed interview data with the participants, following the methodological guidelines outlined by Patton (2002), to ensure data accuracy and gather their input. To maintain confidentiality, we have used pseudonyms when presenting the qualitative findings. In this paper, we refer to the academic researcher as Professor Susana and the Chief Executive Officer of BetaAgritech as Mr Eric. Prof Susana, a professor at UA, also holds the position of Chief Scientist at BetaAgritech.

In accordance with qualitative research practices, we used purposeful sampling to select the case for the pilot study (Yin, 2018). Each selected university startup had to include both an academic researcher and an entrepreneur and hold licensed IPR from a university for the purpose of commercialisation. BetaAgritech is one such startup, and it operates through an accelerator programme at UA. The pilot study's findings were used to triangulate the themes identified through the literature analysis and to gain preliminary insights into the STD undertaken during the Valley of Death phase for IPR commercialisation by university startups.

3. Theoretical background

3.1 Relationship between intellectual property rights commercialisation and technology commercialisation

The Valley of Death is a result of "non-economic activity" during the R&D phase, and Beard *et al.* (2009) stated that this situation arises because most R&D projects are funded by governments and academic researchers do not bear any financial liability or penalty if projects fail to deliver any IPR with commercial value. Hence, the actual and potential commercial aspects of the IPR are often neglected during the early R&D phase. This circumstance typically results in the generation of R&D outputs that are outdated, ambiguous or have no economic value (Auerswald and Branscomb, 2003; Upadhyayula *et al.*, 2018). In some cases, university R&D results in technologies or solutions that do not address a clear problem or market need. This can lead to researchers and founders struggling to find practical, real-world applications for licensed IPR (Shane, 2004).

Hence, startups must use their IPR to develop a specific technological application while exploring its market fit, the market(s) they can enter with minimal resources and how to generate revenue and raise investment as fast as possible. Clearly, it is a significant challenge to develop an early-stage product (Auerswald and Branscomb, 2003; Markham *et al.*, 2010) and find the right market for a product with minimal functional features, known as a minimum viable product, that people are willing to buy (Maurya, 2012).

To give a specific example, when BetaAgritech licensed a patent titled "Preparation of carbon quantum dots" (Abdul Rashid *et al.*, 2018), the founders needed to explore technological applications that make use of quantum dots. Quantum dots, also known as semiconductor nanocrystals, can be used for diverse applications in agriculture (as photosynthesis enhancers; Chowmasundaram *et al.*, 2023), medical diagnostics, drug delivery, gene therapy (Reshma and Mohanan, 2019), photovoltaics (e.g. as solar cells) and catalysis (Cotta, 2020). Using this example of managing a patent that covers the production of carbon quantum dots, we have outlined the process that begins with R&D ideation and concludes with the iteration of a startup business model in Figure 1.

3.2 Using process theories and the resource-based view to explain the intellectual property rights commercialisation process

Van de Ven and Poole (1995) introduced four fundamental theories that can be used as building blocks to elucidate the changes that occur within organisational processes: life cycle, teleology, dialectics and evolution. Each theory offers insights into different stages of organisational development. We suggest using process theories to explain the STD process undertaken by university startups as they navigate the Valley of Death, and here we discuss how these theories can be applied specifically to the challenges faced by university startups during IPR commercialisation.

Life-cycle theory suggests that change occurs at distinct developmental stages and thus provides a systematic framework for explaining IPR commercialisation from the licensing phase to the post-startup phase. As a startup grows and progresses through defined stages – research, orientation, pre-founding and establishment – it faces specific challenges and barriers (Müller-Wieland *et al.*, 2019). Here, these stages are illustrated in Figure 1, which shows how startups pass through an exploratory phase and then an STD phase. During the STD phase, IPR are adapted to meet technical requirements based on the startup's market positioning and business sustainability potential.

Dialectical theory implies that development arises from conflicts and confrontations between opposing entities (Van de Ven and Poole, 1995). When applied to the commercialisation of IPR, this theory explains the transition from an academic setting (i.e. R&D at a university) to an entrepreneurial setting, and this involves the monetisation of IPR through startup formation (Rasmussen, 2011). The commercialisation of IPR by university startups is more complex than that performed by non-university startups, as it involves two distinct groups: academia (including academic researchers and universities) and entrepreneurial stakeholders (e.g. entrepreneurs, venture capitalists and policymakers). Because these two groups often use different language and approaches, bridging the gap

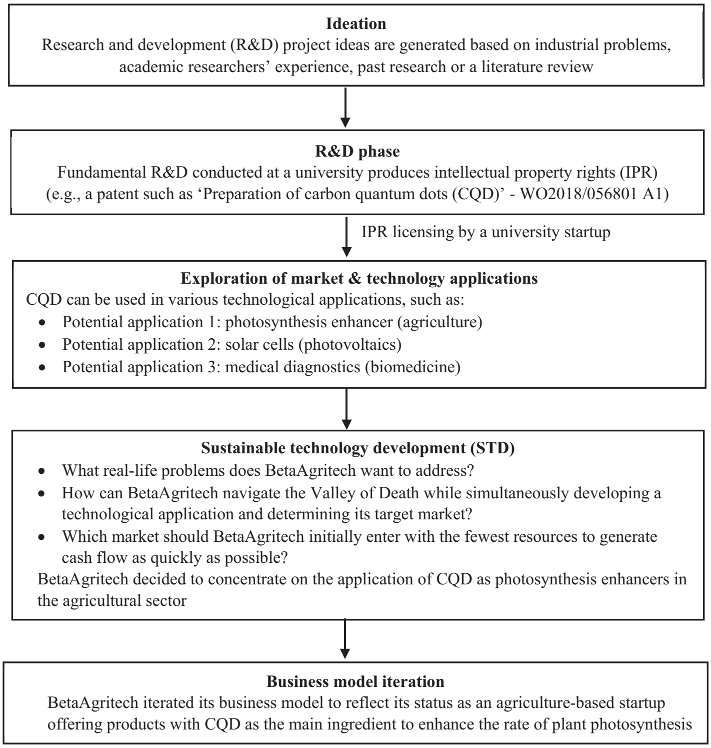

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Figure 1.
Summary of the process that begins with research and development (R&D) ideation and concludes with the iteration of the startup's business model

between academic and entrepreneurial settings presents various challenges. In the context of our study, university-generated IPR may have multiple technological applications, some of which may be highly technical. Therefore, it is crucial to determine which "low-hanging fruit" market the startup should initially target. It is also worth noting that entrepreneurial stakeholders, particularly venture capitalists, assess startups based on their revenue-generating potential and market expansion capabilities (Franke *et al.*, 2008).

Teleological theory emphasises changes in social constructs among individuals within an organisation (Van de Ven and Poole, 1995). In the context of this study, various stakeholders, such as academic researchers, startup entrepreneurs, universities and venture capitalists, assume specific roles at different stages of the commercialisation process. The founders of university startups, who are typically academic researchers and entrepreneurs, serve as the first line of defence when startups must mitigate risks associated with IPR and enter the Valley of Death. These founders are integral to the entire process, from recognising a technology's potential to developing new markets and securing financial investments and support (the awareness and recognition phase) (Clarysse and Moray, 2004; Vanaelst *et al.*, 2006; Markham *et al.*, 2010). They must effectively communicate with various stakeholders within the commercialisation ecosystem to bring the technology to market.

Lastly, evolutionary theory states that there is an ongoing cycle of events that involves variation, selection and retention and is typically influenced by competitive factors (Van de Ven and Poole, 1995). In the context of this study, this theory encompasses unforeseen events, such as the COVID-19 pandemic, which indirectly impact a country's economic landscape and pose threats to startups. Additionally, startups may encounter other challenges, such as technological trends that are not supported by the government or are not favourable for investment by venture capitalists.

STDs within the context of university startups can also be studied through the resource-based view (RBV) lens. The RBV considers a firm as a collection of resources, with managerial resources being the primary driver of firm growth (Barney, 1991; Penrose and Pitelis, 2009). Empirical studies that have investigated the influence of a university's resources and capabilities on the formation and activities of university startups have often used the RBV (Vohora *et al.*, 2004; Lockett and Wright, 2005; Powers and McDougall, 2005; Pazos *et al.*, 2012). For example, Powers and McDougall (2005) used the RBV to explore the impact of specific resources on the number of startups formed and the success of companies that previously licensed IPR from the university in going public. Similarly, Lockett and Wright (2005) used the RBV to assess the influence of university resources and capabilities on the establishment of university startups.

However, because the RBV primarily focuses on the impact of resources, it is limited in its capacity to assess other factors that affect IPR commercialisation by university startups. More specifically, the RBV emphasises internal resources and capabilities as sources of competitive advantage (Barney, 1991; Penrose and Pitelis, 2009) but cannot be used to explain the vital role that external factors, such as market demand, technological trends, government policies and other regulatory requirements, play in the success of IPR commercialisation by university startups (Hossinger *et al.*, 2020). Notably, university startups may have limited control over such external factors. Additionally, as STD of IPR in the context of startups involves multiple stakeholders and processes, adopting an RBV will likely result in overlooking the significance of external relationships and networks, which can be crucial to university startups accessing resources, expertise and market opportunities.

4. Findings

4.1 Redefining the Valley of Death encountered during intellectual property rights commercialisation by university startups

As the bridge between invention and innovation, the Valley of Death is often associated with early-stage technology development (ESTD) (Auerswald and Branscomb, 2003; Markham *et al.*, 2010). While "invention" and "innovation" are sometimes used interchangeably, they have distinct definitions. As stated by Auerswald and Branscomb (2003), "invention" refers to the initial outcome of laboratory R&D and thus represents unvalidated IPR that have yet to demonstrate commercial viability. In contrast, "innovation" is attained when an invention is successfully scaled up and manufactured at a pilot level, becoming ready for the market. Hence, these terms signify different stages of IPR maturity and highlight the continuous enhancement of IPR from various perspectives throughout the commercialisation venture chain.

The positioning of the Valley of Death transitional gap within the commercialisation venture chain can also be identified using the Technology Readiness Level (TRL) scale. Upadhyayula *et al.* (2018) noted that the Valley of Death can occur twice during the process of venturing, specifically at TRL 5–6 and TRL 7. The first Valley of Death occurs when an R&D prototype from a laboratory undergoes upscaling to a pilot or commercial level. The second Valley of Death occurs at TRL 7, which corresponds to the commercialisation phase (Upadhyayula *et al.*, 2018).

Moreover, the Valley of Death can manifest within a startup's operations. As highlighted by Kam-Fai (2020), the Valley of Death experienced by startups typically spans three to five years, with a staggering 90% of these ventures failing because of unfavourable financial outcomes. While there is no precise definition of the Valley of Death that is specifically tailored to startups, it is commonly understood to be the phase during which newly established firms face a shortfall in funding before their newly introduced products or services generate revenue from actual customers (Zwilling, 2013). The Valley of Death thus signifies the period of negative cash flow that precedes the breakeven point.

While there are separate definitions of the Valley of Death for the university and startup contexts, there is no specific definition for the context of university-generated IPR commercialised by university startups. According to the definition that pertains to the university context, most university-generated IPR fail within the Valley of Death. In addition, when a startup acquires university-generated IPR, the Valley of Death phase is typically longer than that encountered when technology is developed by industry players. Therefore, we have conceptualised a definition for the Valley of Death encountered when university-generated IPR are commercialised by university startups that combines aspects of the definitions used for both the university and startup contexts (Table 1). Our definition states that the Valley of Death is "a transitional period during which university-generated intellectual property rights (IPR) acquired by a resource-constrained startup progress from invention to innovation".

Figure 2 illustrates the compilation of existing research on the Valley of Death, which refers to the challenge of transitioning university-generated IPR from basic laboratory research into successful commercial ventures. The figure highlights how different business models can be applied to help bridge this gap during the commercialisation process. Additionally, it emphasises that the Valley of Death can manifest twice within the venture

Table 1. Redefinition of the Valley of Death for intellectual property rights (IPR) commercialisation by university startups

Context	Existing context-based definition	Our proposed definition for the Valley of Death encountered when university-generated IPR are commercialised by university startups
University	• "The gap between federally-funded basic research and industry-funded applied research and development" (Sensenbrenner, 1998) • "Existed in the availability of capital from "basic research" to "commercial operation" in the phase of development and scale-up" (Evans, 2002) • "A gap between the formal roles, activities, and resources poured into research and the existing formal new product development roles, activities, processes, and resources that lead toward commercialization" (Markham *et al.*, 2010)	"A transitional period during which university-generated intellectual property rights (IPR) acquired by a resource-constrained startup progress from invention to innovation"
Startup	• "Represents the period during which early-stage firms endure a cash deficit before their new products or services begin generating revenue from actual clients" (Zwilling, 2013) • "The gap between product launch and when the business becomes successful" (Osawa and Miyazaki, 2006)	

Source: Authors' own work

chain: during TRL 5–6 and TRL 7. The first Valley of Death occurs when a laboratory prototype must be scaled up to a pilot or commercial scale, which is known as the pre-commercialisation phase. Technologies that originate from basic research are typically not suitable for direct end-user applications (Barr *et al.*, 2009).

The second Valley of Death occurs when a startup acquires a technology that requires validation and transformation into a marketable product, and this is known as the startup formation phase (Dean *et al.*, 2022). The y-axis of Figure 2 shows the level of resources throughout the venture chain, while the x-axis shows the various stages of commercialisation. Also indicated are the crucial roles played by stakeholders in the venture chain (teleological theory), the transition from an academic environment to an entrepreneurial one (dialectical theory), and the occurrence of unexpected events, such as environmental changes or pandemics (evolutionary theory), that can influence the commercialisation of a university startup's IPR.

4.2 Conceptualising sustainable technology development during the Valley of Death phase

Generally, technologies that originate from basic R&D conducted in university laboratories (often referred to as early-stage technologies) have not had their on-site technical viability,

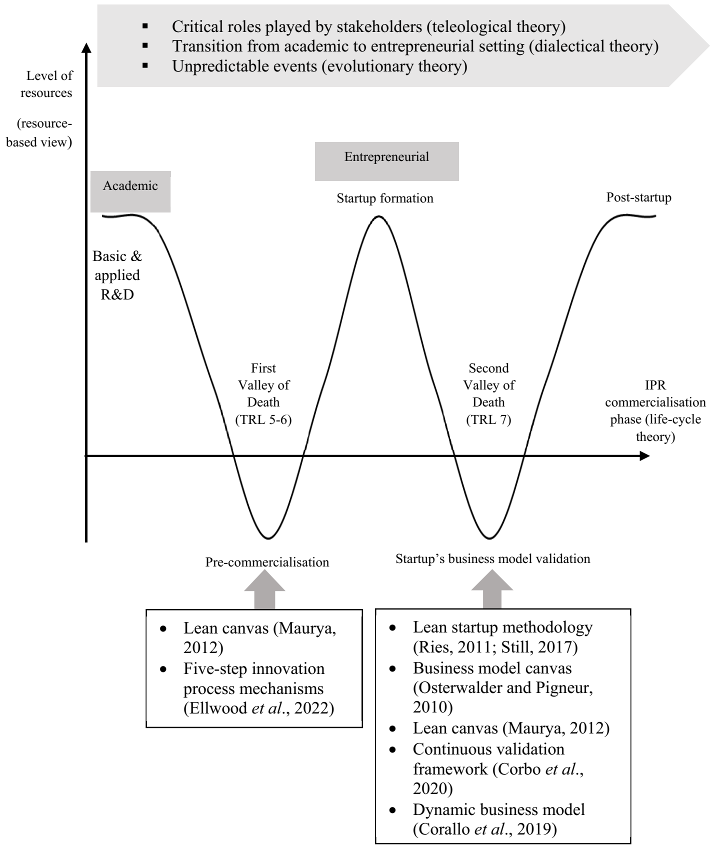

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Figure 2. A synthesis of the literature on crossing the Valley of Death during the commercialisation of university-generated intellectual property rights (IPR) by university startups. Technology Readiness Level (TRL) 5 includes validating the technology in a relevant environment, TRL 6 includes demonstrating it in the same context and TRL 7 represents the stage at which the technology is demonstrated in an operational environment

market potential or scalability for industrial use validated (Barr *et al.*, 2009; Calza *et al.*, 2021; Ellwood *et al.*, 2022). Our literature analysis revealed that for university-generated IPR commercialised by a university startup, STD is comprised of three essential components: market development, technical efficiency and business sustainability (Table 2). Next, we outline management strategies that can be applied to address challenges associated with each of these three components of STD.

To successfully commercialise newly licensed IPR, it is crucial to identify the initial target market segment. This strategic choice guides the development of suitable technological applications tailored to the selected market for the startup's initial market entry. A key challenge faced when managing new technologies lies in the uncertainty of their market potential (Lo *et al.*, 2012; Isasi *et al.*, 2016; Oyesola *et al.*, 2018; Zihare *et al.*, 2018; Li *et al.*, 2019; Li and Mupondwa, 2021; Oluleye *et al.*, 2021). This necessitates startups to engage in a process of testing, validating and, if necessary, pivoting to a different market if the initial prospects do not materialise. Other issues and challenges associated with market development include insufficient user adoption (Verdegem and De Marez, 2008; Schiavone and MacVaugh, 2009), difficulty in gaining customer trust (Obal, 2015) and policy and regulatory hurdles (Bezzina and Terrab, 2005; Hoppner and Gubanova, 2015; Isasi *et al.*, 2016; Mossberg *et al.*, 2018; Oluleye *et al.*, 2021).

In terms of technical efficiency, the issues and challenges faced include those associated with inefficient product design (Bhattacharjya *et al.*, 2019; Alhaj and Al-Ghamdi, 2019), lack of commitment from the inventors (Isasi *et al.*, 2016; Mossberg *et al.*, 2018), technical verification of the technology outside the laboratory, demonstrating proof of concept, conducting clinical trials and scaling up from laboratory scale to pilot scale (Isasi *et al.*, 2016; Mossberg *et al.*, 2018; Bhattacharjya *et al.*, 2019; Li *et al.*, 2019). Economic challenges also arise during the initial stages of commercialisation; startups often have budget constraints that limit their ability to engage in mass production and achieve economies of scale, especially before demand reaches a substantial level. In addition, developing and scaling up certain technologies can involve a high initial cost; for example, establishing a pilot plant or installing solar panels can be expensive (Isasi *et al.*, 2016; Alhaj and Al-Ghamdi, 2019; Li and Mupondwa, 2021).

The choice made by startups regarding their initial market entry significantly influences the technical efficiency of the product or service derived from the licensed IPR. Ultimately, this decision has a cascading effect on various aspects of the startup's business sustainability, including its business model, financial stability and team formation. Startups often undergo continuous change and validation, and their business models can pivot until they establish a clear market penetration plan for long-term revenue generation and positive cash flow (Osterwalder and Pigneur, 2010; Ries, 2011; Blank, 2013). As a result, establishing a viable business model is crucial not only for a startup to progress but also for it to mitigate risks and reduce the likelihood of failure, especially during the Valley of Death phase. In terms of financial stability, factors such as the high operational costs of the technology can significantly impact the startup's sustainability (Isasi *et al.*, 2016; Mossberg *et al.*, 2018; Alhaj and Al-Ghamdi, 2019; Bhattacharjya *et al.*, 2019; Oluleye *et al.*, 2021). Furthermore, close collaboration between the technology inventor and the venture team members is necessary to ensure that the iterative product–market fit process is successful (Ries, 2011; Isasi *et al.*, 2016; Mossberg *et al.*, 2018).

These three components are the foundation for deriving a definition of STD. Therefore, based on the findings of our literature synthesis, we conceptualised a definition of STD. Our definition states that STD is the "continuous development of intellectual property rights (IPR) during the commercialisation process, considering technical efficiency, market

Table 2. Market development, technical efficiency and business sustainability challenges and management strategies

Perspective	Issues and challenges	References	Management strategies
Market development	Market uncertainty	Jalonen (2012), Sadeh and Dvir (2020)	Validated learning: experimentation, data collection and validation of assumptions (Ries, 2011)
	Insufficient user adoption	Verdegem and De Marez (2008), Schiavone and MacVaugh (2009), Knight and Burn (2011)	Niche market positioning (Slater and Mohr, 2006; Pascaris *et al.*, 2023)
	Difficulty in gaining customer trust	Obal (2015)	Strategic partnership (Hashai and Markovich, 2017), development of business cases (Kruachottikul *et al.*, 2023)
	Regulatory hurdles	Bezzina and Terrab (2005), Hoppner and Gubanova (2015), Isasi *et al.* (2016), Mossberg *et al.* (2018), Oluleye *et al.* (2021)	Product integration strategy (Nambisan, 2002), new policies and regulations (Hoppner and Gubanova, 2015)
Technical efficiency	High development cost	Isasi *et al.* (2016), Mossberg *et al.* (2018), Alhaj and Al-Ghamdi (2019), Bhattacharjya *et al.* (2019), Oluleye *et al.* (2021)	Government grants and funding (Islam *et al.*, 2018; Zhao and Ziedonis, 2020), co-sharing and strategic partnership (e.g. university–industry collaboration) (Schiuma and Carlucci, 2018)
	Scalability and economies of scale	Isasi *et al.* (2016), Li and Mupondwa (2021), Alhaj and Al-Ghamdi (2019)	Outsourcing (Steinbruch *et al.*, 2022), scalable production process (Mossberg *et al.*, 2018), pricing strategy (Gómez-Prado *et al.*, 2022)
	Technical feasibility	Isasi *et al.* (2016), Mossberg *et al.* (2018), Bhattacharjya *et al.* (2019), Li *et al.* (2019)	Prototyping and testing (Kruachottikul *et al.*, 2023)
Business sustainability	Financial	Damodaran (2009), Ferrucci *et al.* (2023), Saleem and Atiq (2023)	Bootstrapping (Smith, 2009), raising investment (Nanda and Rhodes-Kropf, 2013), revenue generation (Laitinen, 2019)
	Team	Isasi *et al.* (2016), Mossberg *et al.* (2018), Hossinger *et al.* (2020)	Cross-complementary skills and expertise (Clarysse and Moray, 2004), motivation and sharing the same end goals (Clarysse and Moray, 2004; Vanaelst *et al.*, 2006)
	Business model viability	Nunes *et al.* (2022)	Lean model canvas (Ries, 2011), Business model canvas (Osterwalder and Pigneur, 2010)

Source: Authors' own work

development and business sustainability". By ensuring STD during the Valley of Death phase, the success of IPR commercialisation by university startups can be enhanced. We further propose a framework for STD, the STDF, as illustrated in Figure 3.

4.3 Potential dynamics of relationships among the components of sustainable technology development

The three components of STD are closely interconnected when a startup licenses university-generated IPR. These components interact with one another in a dynamic and interdependent manner that ultimately influences the overall success of the startup (Figure 4). In this section, we use qualitative case study data obtained from semi-structured interviews with BetaAgritech's founders to provide support for our conceptualisation of STD and its components.

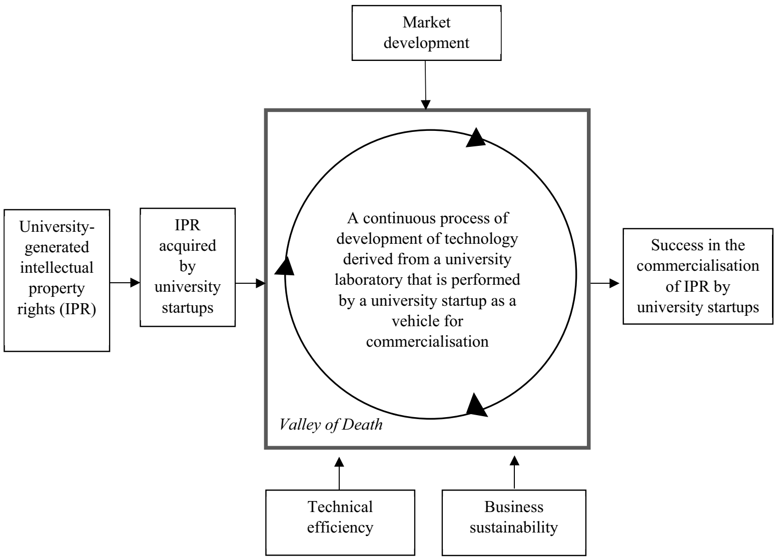

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Figure 3. Proposed conceptual sustainable technology development framework (STDF)

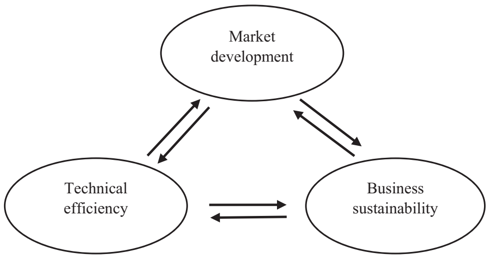

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Figure 4. Interconnected components of sustainable technology development for university startups

Technical efficiency and market development: The technical aspects of the technological applications of licensed IPR are strongly influenced by market readiness. A startup's ability to develop and refine its licensed technology is a fundamental factor in determining how quickly it can bring its products or services to market (Maurya, 2012). In the case of BetaAgritech, the founders mentioned that as they explored potential applications of the IPR, they decided to focus on the agricultural sector, given that UA is an agricultural university. Their goal was to target the "lowest-hanging fruit" market, which was home gardening. This decision was driven by the fact that the product was initially produced at the laboratory scale, which led to challenges related to economies of scale. Mr Eric stated that:

> The market is a challenge because when we are still producing at a small scale, the cost is relatively high and that's why we need to price our product at a relatively higher price as well. This higher price may not be attractive to some farmers who are planting low-value crops. So that's why we are targeting the home gardening sector and the rare plant collectors because they are willing to spend on their rare and expensive plants so they don't mind paying a slight premium to photosynthesis enhancers.

When BetaAgritech approaches various segments of potential customers, it gathers feedback from the market. This feedback loop is crucial to the process of fine-tuning the technology so that it effectively meets the target markets' needs and product–market fit is achieved (Maurya, 2012).

Market development and business sustainability: Expanding the market and acquiring new customers are critical for generating revenue and achieving business sustainability. As their customer base grows, BetaAgritech's revenue increases, and this ensures the business sustainability of the startup. New technology should be positioned in a specific niche market segment where there are early adopters willing to pay for its usage before it gains widespread acceptance. Once the niche market is established, efforts should be made to explore other potential applications of the technology to expand the market size. In the case of BetaAgritech, Mr Eric mentioned:

> In regard to the further development of the technology, our exclusive licensing primarily pertains to the production of quantum dots. (. . .) we have the flexibility to utilise quantum dots in various applications that are also covered under the same IPR. (. . .) Our aim is to validate different applications and identify potentially high-value sectors. For instance, solar cells could be one such sector, and healthcare could be another.

Technical development and business sustainability: Ongoing technical development can help a startup maintain a competitive advantage. The technical aspect of a technology should be verified and further developed based on feedback from field trials or communication with potential buyers or end users. In the case of BetaAgritech, Mr Eric mentioned that in response to feedback from clients who found the price of their photosynthesis enhancer expensive, they needed to develop and scale up a different formulation of their original product to cater to the mass market:

> I believe the pivotal point occurs after we scale up our operations. Once we've successfully upscaled, we can lower our prices. This, in turn, will make our product more economically accessible to a broader range of farms, particularly those with lower-value crops. With mass market adoption, I don't foresee sustainability being a problem for us.

Nevertheless, BetaAgritech has encountered a scaling-up barrier with the microwave process, which is part of the carbon quantum dots production method, creating a bottleneck. According to Prof Susana:

> The bottleneck in our process is the microwave process. I would say the barrier to scaling up this technology would be if we are unable to scale up the microwave process. This limitation could result in increased production times.

In summary, these three components are closely interrelated and create a feedback loop that can either propel a startup towards sustainability or hinder its progress. Hence, it is important for startups to balance technical efficiency and market development to ensure that they are building products or services derived from the licensed IPR that address real market needs. This, in turn, supports long-term business sustainability by driving revenue growth, enhancing the startup's competitive advantage and achieving the best outcomes with minimal resources. Ultimately, a well-executed strategy that considers these three components can facilitate the success of a startup in a competitive landscape.

5. Implications

This research was motivated by the high failure rate of IPR commercialisation observed in university startups, especially at the initial development stage. Several studies have shown that the commercialisation of IPR that emanate from university laboratories often fails during the Valley of Death phase (Branscomb and Auerswald, 2002; Markham, 2002; Evans, 2002; Osawa and Miyazaki, 2006; Barr *et al.*, 2009; Ellwood *et al.*, 2022). The high rate of startup failures (Blank, 2013) worsens this scenario.

The commercialisation of IPR by university startups carries significant social and economic implications. It serves as a conduit for transferring knowledge from academic research to practical applications, which benefits society as a whole. Moreover, the formation of technology startups promotes job creation among highly skilled people and enhances graduate employability (Davey and Galan-Muros, 2020), thereby stimulating regional economic development. Increasing the success rate of IPR commercialisation by university startups would encourage the creation of more startups, which would ultimately strengthen a nation's competitiveness and global innovation index (Caputo *et al.*, 2022).

In terms of theoretical implications, the findings of this study have the potential to advance process theories related to STD within the context of the Valley of Death phase encountered by university startups and thus contribute to a deeper understanding of technology transfer. Additionally, the findings of this study could be used to further elucidate the boundary conditions of process theories, including the "who, where and when" aspects of such theories (Busse *et al.*, 2017), by providing a new construct and information on its relationship with existing important STD constructs. Thus, the findings of this study advance our understanding of the relationship between commercialisation and STDs.

6. Limitations and future directions

This study focused on a novel research area: the sustainability of technology development during the IPR commercialisation process, and specifically during the challenging Valley of Death phase. A key outcome of this study was the creation of the STDF, which is designed to enhance the success of IPR commercialisation by university startups. Hence, empirical research involving the qualitative analysis of multiple case studies is needed to test, refine and validate the proposed conceptualised STDF. Here, we outline some potential research questions that could serve as starting points for investigating the multifaceted aspects of STD in the context of university startup ventures engaged in IPR commercialisation:

- What factors influence the selection of technology commercialisation strategies by university startups, and how do these strategies impact STD?
- How do university startup ecosystems, which include incubators and accelerators, influence the STD outcomes of startups engaged in IPR commercialisation?
- What are the critical success factors and best practices for achieving STD during the commercialisation of university-generated IPR, and how do they vary across different technology domains?

In addition to qualitative research, quantitative research should also be conducted to generate empirical evidence of the proposed relationship between the technical efficiency, market development and business sustainability of IPR commercialisation by university startups. For instance, a regression analysis could be performed to assess how changes in technical efficiency metrics correlate with shifts in market development indicators or measures of business sustainability.

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