UNIVERSITY OF TURKU

THE COMMERCIALIZATION PROCESS OF HIGH TECHNOLOGIES

Case Studies of High Technologies from ICT, Cleantech and Life Sciences Industries

Saheed Adebayo Gbadegeshin

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ABSTRACT

Commercialization of high technologies refers to a process that transforms radical and disruptive innovations into consumable products, services and solution packages. This process generates returns on research and development investments, employs highly educated people, empowers semi-skilled persons and makes business enterprises prosperous and sustainable. Hence, this study investigated the commercialization process purposely to provide in-depth knowledge of it. The study aimed to investigate how high technologies are commercialized, especially in ICT, Cleantech and the Life Sciences industries to provide a better understanding of the commercialization process. This understanding is essential due to the increase in new high technologies and rapid changes in these industries.

The study employed a case study research method to achieve its goal. It used interviews, an online survey, observations and documentary for data collection, and content and thematic methods for data analysis. It used primary and secondary data that were collected between 2012 and 2017. Its participants represented stakeholders of the above-mentioned industries. The participants mostly came from Finland, but some came from other European countries.

The study found that the commercialization process models are rooted in the Technology Acceptance Model (TAM), Unified Theory of Acceptance and Use of Technology (UTAUT), Stage-gate, Effectuation, Bricolage and Lean Start-up theoretical frameworks. Similarly, it found that the process makes use of a mixture of linear and non-linear logic. Additionally, it found that the commercialization process starts during the pre-innovation phase and continues after the innovation's marketing phase, and that commercialization activities must be performed in parallel (simultaneously). Most interestingly, the study revealed that digitalization has changes on the commercialization process.

Based on the findings, the study proposed a new model for commercializing high technologies in the above-mentioned industries; a framework termed the

"Integrative Commercialization Process" (ICP). The model was built on theories, theoretical frameworks and models of the innovation process, New Product Development (NPD), Entrepreneurship, Spinoff, Transfer of Technology (TOT) and Marketing. Similarly, the model was built on the context of ICT, Cleantech and the Life Sciences. Hence, the study offered insights into the theoretical frameworks of the innovation, the NPD, Spinoff and marketing fields. Furthermore, the study provided practical insight for the stakeholders of the aforementioned industries, especially potential entrepreneurs (e.g., scientists and engineers), technology entrepreneurs, entrepreneurship educators, commercialization practitioners, universities and research institutes and companies. Therefore, this study makes contributions to the theory and practice of commercialization.

Keywords: Commercialization Process, High Technology, ICT, Cleantech, Life Sciences, Finland

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TIIVISTELMÄ

Korkean teknologian kaupallistamisella viitataan prosessiin, jossa radikaalit ja disruptiiviset innovaatiot kehittyvät kulutettaviksi tuotteiksi, palveluiksi tai ratkaisuiksi. Kaupallistaminen tuottaa vastinetta tehdyille investoinneille, työllistää koulutettuja ihmisiä sekä luo menestyvää ja kestävää liiketoimintaa. Tässä väitöskirjassa on tutkittu kaupallistamisprosessia ja tuotettu syvällisempää uutta tietoa siitä. Tutkimuksen tavoitteena oli selvittää millä tavoin korkean teknologian kaupallistaminen tapahtuu, erityisesti ICT-, Life Sciences-, sekä Cleantech – aloilla sekä tuottaa parempaa ymmärrystä kaupallistamisprosessista näillä aloilla. Näillä teknologianaloilla kasvu on nopeaa ja isoja muutoksia tapahtuu jatkuvasti. Korkean teknologian kasvavasta merkityksestä ja nopeista muutoksista johtuen näiden alojen kaupallistamisprosessin ymmärtäminen on erittäin tärkeää.

Tutkimus on toteutettu tapaustutkimuksena. Tutkimusaineistoa on kerätty haastatteluin sekä kyselytutkimuksen, dokumenttiaineiston ja havainnoinnin keinoin. Tutkimusaineisto on analysoitu sisältöanalyysin sekä temaattisen analyysin avulla. Primäärinen ja sekundäärinen tutkimusaineisto on kerätty ajanjaksolla 2012-2017. Tutkimukseen informantit ovat yllämainittujen alojen edustajia. Suurin osa informanteista oli Suomesta, mutta joitakin osallistujia oli myös muista Euroopan maista.

Tehdyn tutkimuksen perusteella kaupallistamisen prosessi pohjautuu Technology Acceptance-malliin (TAM), Unified Theory of Acceptance and Use of Technology (UTAUT) -teoriaan, sekä Stage-gate-, Effectuation-, Bricolage-, ja Lean Start-up -viitekehyksiin. Samoin tutkimuksessa havaittiin, että prosessi on yhdistelmä lineaarista ja epälineaarista logiikkaa. Lisäksi havaittiin, että kaupallistamisprosessi alkaa jo ennen innovaatiovaihetta, jatkuu vielä innovaation markkinointivaiheen jälkeen sekä edellyttää eri kaupallistamisaktiviteettien samanaikaista toteuttamista. Mielenkiintoista on, että digitalisaatio muuttaa kaupallistamisprosessia.

Tutkimustuloksiin perustuen, tutkimus esittää uuden mallin korkean teknologian kaupallistamiseksi edellä mainituilla toimialoilla: ”Integrative Commercialization Process” (ICP). Tämä malli perustuu teorioihin, teoreettisiin viitekehyksiin sekä innovaatioprosessin malleihin: uuden tuotteen kehittämisprosessi (New Product Development, NPD), Yrittäjyys (Entrepreneurship), Spinoff-prosessi, teknologiansiirto (Transfer of Technology, TOT) ja markkinointi (Marketing).

Malli on rakennettu ICT-, Cleantech- sekä Life Science-alan konteksteissa ja se tarjoaa uusia näkökulmia innovaatioiden teoreettisiin viitekehyksiin, uuden tuotteen kehittämisprosessiin, spinoff-toimintaan sekä markkinointiin. Lisäksi tutkimus tarjoaa käytännön tietoa yllämainittujen alojen sidosryhmille, erityisesti potentiaalisille yrittäjille (esimerkiksi tutkijat ja insinöörit), teknologiayrittäjille, yrittäjyyden kouluttajille, kaupallistamisen asiantuntijoille, yliopistoille, tutkimuslaitoksille ja yrityksille. Tämä tutkimus tuottaa kontribuutiota niin kaupallistamisen tieteelliseen keskusteluun kuin käytäntöön.

Avainsanat: Kaupallistamisprosessi, korkea teknologia, ICT, Cleantech, Life Sciences, Suomi

DEDICATION

This study is dedicated to my parents, Adigun and Aduke Gbadegeshin, whose love for education made me a scholar. Without their dedication to my education, I do not know where I would be today.

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Saheed Adebayo Gbadegeshin
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Article 2: Gbadegeshin, S. A. (2017b) Commercialization Process of High Technologies: Case Study of Finnish University Spin-off. *Academy of Entrepreneurship Journal*, Vol. 23 (2), 1–22.

Article 3: Gbadegeshin, S. A. (2018a) Lean Commercialization: A Framework for Commercializing High Technologies. *Technology Innovation Management Review*, Vol. 8 (9), 50–63.

Article 4: Gbadegeshin, S. A. (2019b) The Effect of Digitalization on the Commercialization Process of High Technology Companies in the Life Sciences Industry. *Technology Innovation Management Review*, Vol. 9 (1), 49–63.

PART 1:
SYNOPSIS OF THE STUDY

1 INTRODUCTION

The number of new high technologies is currently increasing. These technologies are characterized by high levels of research and development (R&D) activities, process and product complexities, uncertainties and resource intensiveness (Wong 1990; Steenhuis & De Bruijn 2006). The huge investments on them means they must be commercialized. Commercialization refers to converting the technologies into consumable products and services (Nevens et al. 1990). In fact, these technologies must be diffused in a short time due to constant changes (Risselada et al. 2014; Chanda & Das 2015); therefore, knowledge about commercialization process is essential (Pellikka 2014; Aarikka-Stenroos & Lehtimäki 2014). In respect to the need for knowledge and the importance of commercializing high technologies, this doctoral thesis focuses on the commercialization process to provide an in-depth understanding of the process.

1.1 Background and Scope of the Study

The term *commercialization* is described as a transformation of new technology and knowledge into products and services (Michael 1990). It is also described as an effort to make inventions or innovations that are commercially useful as well as beneficial for society (Pellikka & Malinen 2011; Tahvanainen & Nikulainen 2011). Thus, the *commercialization process* refers to a series of activities involved in transforming innovations into products or services (Nevens et al. 1990). It also refers to entire activities of making high technologies available to the market and society (Pellikka & Malinen 2011).

Thus, the commercialization process is multidisciplinary, connoting many fields of study. It is well-connected to innovation, entrepreneurship and marketing. Most previous works, such as Michael (1990), Nevens et al. (1990) and Aarikka-Stenroos and Lehtimäki (2014), discussed the process from either one field or from a combination of multiple. Similarly, the commercialization process is widely and scholarly discussed in relation to new product development (NPD), Spinoff and transfer of technology (TOT). Examples of the discussion can be found in the work of Cooper (1990), Pimay et al. (2003) and Bradley et al. (2013).

Furthermore, many previous works on the commercialization process adopted different points of view. For example, Slater and Mohr (2006) and Frattini et al.

(2012), explained the process from a strategic point of view. Likewise, Kalaitzandonakes (1997), Gans and Stern (2003), and Dhebar (2016) discussed the process from a marketing perspective. Additionally, Chandler (2005) and Fletcher and Bourne (2012) discussed it from a skill perspective. Meanwhile, these standpoints are closely related to the above fields. Therefore, investigating the commercialization process in relation to the previously listed fields would provide in-depth understanding of the process. Hence, this study investigates the commercialization process by considering various theoretical frameworks of the fields. However, this study does not emphasize the entirety of each field; rather, it focuses on a few theories, theoretical frameworks and models that relate to the commercialization process.

Notably in this study, *theory* refers to key knowledge in the above-mentioned fields, while *theoretical framework* refers to the scholarly frameworks that are developed and applied in the fields. Similarly, *model* refers to a theoretical framework that is developed from the theory and empirical findings. Thus, the theories were used in this study to provide foundational knowledge, and theoretical frameworks and models were used to provide supported knowledge. Both theoretical frameworks and models are used interchangeably in this study.

Similarly, it is worth noting that this study focuses on the entire commercialization process of high technologies. As noticed, most of the previous works investigating the commercialization process were mostly done in relation to the innovation process. This is established in the work of Veryzer (1998), Vowles et al. (2011), and Robbins and O'Gorman (2014). Meanwhile, there are many fields and many different forms of innovation associated with the process. The most common forms of innovation are incremental and radical (disruptive). According to Rice et al. (2002) and Garcia and Calantone (2002), radical and disruptive innovations are associated with the high level of R&D activities, uncertainties and complexities. These scholars add that radical and disruptive innovations can cause changes in the existing ecosystem. In respect to their definition of innovation, high technologies make use of radical and disruptive innovations. According to Schrier and Hallin (2017), *high technologies* are described as cutting-edge technologies that are closely related to advanced technological development and economic growth. Thus, this study centers on the high technologies that include innovations.

Based on the above background and clarification, the following paragraphs present the scope of the study. The fields are firstly presented and are followed by empirical context.

In the first field, ***Innovation***, commercialization is regarded as the last stage of its process. This is asserted by scholars who claimed that the innovation process is linear (e.g., Myers & Marquis 1969). These scholars state that a popular three-stage model, which consists of basic research, applied research and development,

depicts the entire process of innovation. Conversely, some scholars argued that the process is not linear (e.g., Mowery & Rosenberg 1979; Rothwell & Zegveld 1985). This school of thought also regards the commercialization process as the last two stages of the innovation process. From both schools of thought, it can be agreed that they consider the commercialization process as part of the innovation process, as it is shown in the work of Godin (2006) and Aarikka-Stenroos and Lehtimäki (2014). Therefore, the innovation field is an important discipline for investigating the commercialization process. However, the innovation literary works (e.g., Freeman & Soete 1997; Veryzer 1998) note that when commercialization is discussed in relation to the innovation process, limited attention is paid to high technologies. Thus, this study concentrates on the high technology commercialization process as part of the innovation process; it also examines the arguments of both schools of thought—linear and non-linear logic—on the process.

The second field, ***NPD***, sees commercialization as an integral part of its process. It is observed from the previous works on commercialization (e.g., Maine & Garnsey 2007; Pietzsch et al. 2009; Grönlund et al. 2010) that NPD theoretical frameworks are much closer to commercialization models. This is also shown in the work of the main NPD theorist, Cooper (1990), who explains that the NPD framework starts with an idea, which is later developed into a new product or service. The idea is the starting point of innovation, and it passes through the development phase, termed the Stage-gate system. Succinctly, NPD consists of pre-innovation, innovation and post-innovation activities. This combination is also noted in other NPD works, such as Calantone and di Benedetto (1988) and Veryzer (1998). Thus, it can be agreed that NPD combines the innovation and commercialization processes. In turn, it can be agreed that NPD is crucial to the discussion of the commercialization process. Meanwhile, the above-mentioned NPD scholars do not seem to consider how the commercialization process might change the entire NPD. Similarly, the NPD scholars seem to employ a linear logic in which many innovation scholars (e.g., Rothwell 1994; Marinova & Phillimore 2003), argue that such logic does not reflect the reality of the commercialization process. Thus, this current study examines the commercialization process through the NPD process of high technologies and investigates whether the process is or is not linear.

The third field, ***Entrepreneurship***, regards commercialization as a part of its process. The entrepreneurship process refers to entire activities, actions and functions in recognizing and utilizing opportunities through creation of organizations (Bygrave & Hofer 1991; 14). This definition seemed to prompt some scholars like Kruger (2004) who explained that exploitation of opportunity gained ground among entrepreneurial theorists, because it depicts the entrepreneurship process and its activities. The scholar noted that: *it will be necessary to focus further on the processes underlying the 'activity-based' concepts in order to reach more*

clarity on creativity and innovation in the entrepreneurship domain (p. 37-38). Similarly, Keskin et al. (2013) explained that the process starts from *intended value* and ends with *value created*. Along the process, Keskin et al. (2013) explained that opportunity creation and realization are achieved through the ideation, design and commercialization phases. This process appears to be linear and regards commercialization as its final stage. Furthermore, the work of Steyaert (2007) stated that entrepreneurial process theories express different views, which are the creative, discovery and evolutionary theoretical views. All these views seem to employ a mixture of linear and non-linear logic. Specifically, the creative view deals with uncertainty and complexity situations. Examples of creative process theories are the Effectuation, Bricolage and Lean approaches. Hence, it can be agreed that the field of entrepreneurship is relevant to the commercialization process of high technologies. Therefore, this study examines how these creative process theories treat the commercialization process as a part of the entrepreneurship process and their logics.

The fourth field, the ***Spinoff*** process, resembles the NPD and entrepreneurship processes. It seems to combine both processes. Spinoff is defined as creation of a new business venture with a purpose to realize commercial benefits of R&D results or inventions from academic institutions, public research centers and private organizations according to Mustar et al. (2006), De Cleyn and Braet (2009), and Helm et al. (2013). This definition shows that pre-innovation, innovation and post-innovation activities are included in the Spinoff process. Hence, the commercialization process is a part of the process. Additionally, some literary works, such as Ndonzuau et al. (2002), Vincett (2010), and Grimaldi et al. (2011), revealed that Spinoff is one of the commercialization methods. These works state that Spinoff is often discussed as academic entrepreneurship, university Spinoff, academic Spinoff, a research-based enterprise and new technology-based firms. Therefore, the Spinoff process contains the commercialization process. Hence, it can be agreed that Spinoff has a close relationship with the commercialization. The Spinoff can offer insight into the commercialization process. However, most of the previous scholarly works on Spinoff focused on specific actors of the commercialization process. For instance, Carayannis et al. (1998) and Fontes (2005) focused on idea-originating organizations (e.g., university, parent organization and research institutes), while others, such as Mustar (1997) and Franklin et al. (2001), focused only on entrepreneurs (e.g., researchers and students) that execute commercialization activities. The current study investigates the commercialization process by considering all actors and activities of the process over a period.

The fifth field, ***TOT***, is similar to the Spinoff, the NPD and entrepreneurship processes. Most scholars who discussed Spinoff, which include Hindle and Yencken (2004), Bradley et al. (2013) and Al Natsheh et al. (2014), also explai-

ned TOT. Their literary works showed that TOT serves as a theoretical background for the Spinoff. Similarly, the above works on NPD and Spinoff showed that TOT theoretical frameworks are almost the same as the NPD models. Drawing upon Douthwaite et al. (2002), TOT consists of pre-innovation, innovation and post-innovation activities. Therefore, TOT is an essential field to examine the commercialization process. However, the TOT theoretical frameworks seem to employ linear logic, which some Spinoff scholars such as Seguí-Mas et al. (2016) and Shakeel et al. (2017), are rebutting due to complicated Spinoff activities and the uncertainties and complexities of high technologies. Thus, this study examined TOT as part of the Spinoff process and its logic (either linear or non-linear).

The last field, ***Marketing***, considers commercialization from the strategy point of view. The marketing scholars Cooper (2000), Mohr and Sarin (2007) and Aarikka-Stenroos and Lehtimäki (2014) state that the marketing strategy for the commercialization of high technologies seems to be different from common or matured technologies. To propose strategies and tactics, these scholars emphasize the differences between high and low technologies. Some literary works on the innovation (e.g., Anderson et al. 2014; Barbieri & Alvares 2016), NPD (e.g., Frishammar et al. 2016; Pereira et al. 2017), entrepreneurship (e.g., Keskin et al. 2013), Spinoff (e.g., Pimay et al. 2003; Helm et al. 2013) and TOT (e.g., Bradley et al. 2013; Al Natsheh et al. 2014) showed that the commercialization process is synonymously referred to as marketing. Therefore, commercialization denotes marketing. Hence, it can be deduced that employing marketing knowledge to examine the commercialization process is sensible. Meanwhile, marketing of high technologies is different from low technologies. To provide knowledge on the marketing of high technologies, this study investigates the commercialization process in respect to work of Valiauga (2013), Tanev and Frederiksen (2014) and Dhebar (2016). These scholars argued that the commercialization process would be better understood if the marketing aspect of the high technologies could be probed.

From the preceding, it can be deduced that the fields have important roles in the commercialization process. It can be also assumed that existing knowledge from the fields can offer insight into how to investigate the commercialization process. Therefore, this study made use of the literature from the fields and its theoretical background was based on the theories, theoretical frameworks and models of the fields. Figure 1 shows the study's scope, and chapter 2 presents its details in section 2.4.

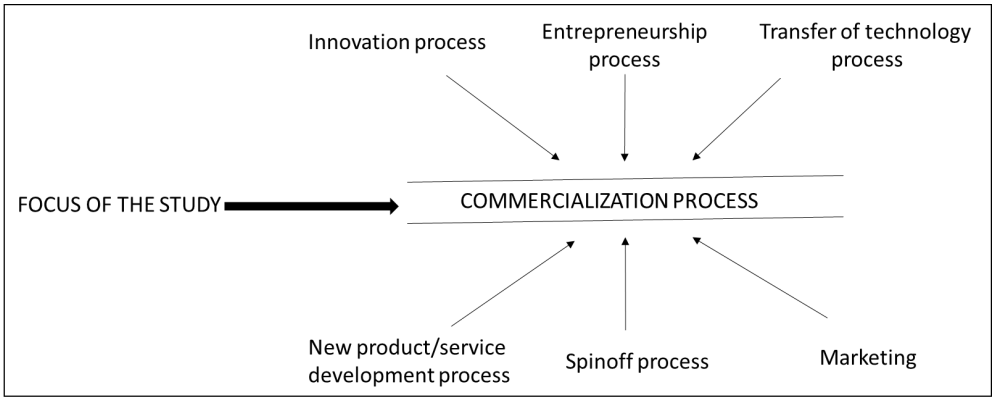


Figure 1: Scope of the Study

High technologies vary in their development processes, from company to company and from one industry to another. Hence, the commercialization processes differ and they need to be studied in their context (where they occur). This study investigates the process contextually. *Contextualization* refers to placing a study phenomenon into a specific environment (Welter 2011). Some previous works on the commercialization process are contextualized, as shown in Szuhaj and McCullough (2009) and Nassiri-Koopaei et al. (2014), who focused on the biopharmaceutical industry. To gain more in-depth understanding of the process and its complexity, the current study focuses on three industries: information and communication technologies (ICT), Cleantech and the Life Sciences. These industries have many high technologies; thus, investigating their processes would provide more insights into the complexity of the commercialization process.

According to Baker and Welter (2018), it is essential to limit the generality of research, especially for entrepreneurship studies. These scholars argued that contextualizing a study would provide in-depth knowledge of the research phenomenon. They also add that contextualized studies enable researchers to provide useful information for their audiences and make such studies have a positive impact on teaching. Similarly, Welter (2011) states that the contextualization of empirical studies promotes a multidisciplinary perspective and facilitates a broader view of a certain phenomenon. With respect to the arguments of these scholars, this study focuses on the companies from the above-mentioned industries. Specifically, the companies that deal with information systems, electronics and optics were considered in the ICT industry, while companies that produce measurement and renewable energy technologies were considered to fall into the Cleantech industry. For the Life Sciences, new drug development (NDD) and medical device and e-health companies were considered. Detailed information on the context of the study is provided in section 1.4.

1.2 Objectives and Research Questions of the Study

Some scholars such as Baptista and Preto (2009), Banerjee and Cole (2011) and Tahvanainen and Nikulainen (2011) have established that the commercialization of high technologies plays a significant role in the national economy. One of its contributions is the generation of return on investments for R&D activities, according to Cornford (2002). Another contribution is that it makes business enterprises prosperous and sustainable (Ulrich & Eppinger 2011; Kahn et al. 2013; Al Natsheh et al. 2015). Additionally, commercializing high technologies employs highly skilled people, empowers semiskilled people, facilitates production activities and provides added value to society (Aydalot & Keeble 2018). Therefore, Brettel et al. (2016), Parviainen et al. (2017) and Gbadegeshin (2018a) have argued that new technologies must be commercialized. These scholars stated that the commercialization of high technologies needs flexible and cost-effective models that mitigate risks and uncertainty. Hence, some scholars, such as Harrer and Smith (1987), McCoy et al. (2008) and Datta et al. (2013), called for an intensive study of the commercialization process for better understanding. In responding to these scholars and to contribute to the discourse on the commercialization process, the current study aims:

> ***To investigate how high technologies are commercialized, especially in ICT, Cleantech and the Life Sciences industries.***

To achieve the above goal, research questions were developed. According to Agee (2009) and Rojon and Saunders (2012), having the right objectives is a prerequisite for developing and addressing research questions. Hence, the first research question of this study emanated from the work of Tahvanainen and Nikulainen (2011), Chiesa and Frattini (2011), and Pellikka et al. (2012). These scholars demanded further studies on possible problems that hinder the commercialization process of high technologies. These scholars and others, such as Prebble et al. (2008), Balachandra et al. (2010), and Lavoie et al. (2017), argued that understanding the commercialization's challenges would provide plausible knowledge on its process.

Therefore, some previous works on the challenges of the commercialization process were reviewed. The review was done by searching for scholarly articles on these challenges, collating relevant articles, reading and coding them, and summarizing their codes. This process was done in line with recommendations from Steward (2004) and Torraco (2005). The reviewed works revealed that the general problems include marketing, management, patent filing, motivation, policy, human resources, technology incompatibility and most importantly, financing. It is noted that some of the reviewed studies investigated specific industries,

such as bio-pharmaceutical (e.g., Nassiri-Koopaei et al. 2014), nanotechnology (e.g., Pfautsch 2007; Kaarela 2013), food and agriculture (e.g., Bochlje 2004), health and medical (e.g., Booz Allez Hamilton et al. 2012; Scanlon & Lieberman 2007), and electricity (e.g., O'Brien et al. 2004). Despite differences in the industries, these studies found that a low-level understanding of technology transfer and intellectual property (IP), insufficient entrepreneurial skills and regulation and legal issues are the main obstacles to the commercialization. The scholars of these studies also agreed that the general problems posed challenges for commercialization of high technologies.

Meanwhile, considering that the high technologies are a capital-intensive activity with various uncertainties, other obstacles may be facing them. Thus, the current study assumed that there might be other challenges, especially in the industries that have not yet been focused (their commercialization processes), such as ICT and Cleantech. Therefore, this study's first question research question (RQ) is:

> ***RQ1: What are the challenges of the high technologies' commercialization process?***

The study's second RQ originated from the work of Eldred and McGrath (1997), Grönlund et al. (2010), and Holzleitner (2015). These scholars asserted that knowledge of commercialization models would enable a better understanding of the commercialization process. They recommended that the development of a commercialization model that is flexible and cost-effective would facilitate the commercialization process because existing commercialization process models are stage-based. Additionally, other scholars such as Amadi-Echendu and Rasetlola (2011) and Högman and Johannesson (2013) claimed that a commercialization model should consider the realities of the process, which is characterized by complexity and uncertainty. The stage-based scholars, which include Maine and Garnsey (2007) and Pietzsch et al. (2009), explained that specific activities are performed at a certain stage before moving to the next stage in their models. Their models start with discovery and end with the launching and marketization of a new product or service developed from high technology. Conversely, non-stage-based scholars explained that there should be iterations and feedback loops among commercialization activities. The non-stage-based scholars, Amadi-Echendu and Rasetlola (2011) and Högman and Johannesson (2013, argued that the process should be circular or continuous instead of a *one-way-trip*. Likewise, the recent works from Cooper (2014; 2017), Cooper and Sommer (2016), Conforto and Amaral (2016) and Gbadegeshin (2017b) claimed that the process should be not only flexible and adaptive, but its activities should also be performed simultaneously (in parallel). Therefore, it seems to be important to know

how the commercialization models (from both groups) produce knowledge for commercializers of the high technologies and to know whether they are still relevant in today's business environments. It also seems important to know whether the high technologies' commercialization process is stage-based or not.

Additionally, the second RQ was derived from the work of Slater and Mohr (2006), Frattini et al. (2012) and Fletcher and Bourne (2012), who recommended that some factors need to be considered in the commercialization process. These scholars pinpointed that researching internal factors of technology-based companies would contribute to understanding the commercialization process. Examples of internal factors of the commercialization process are decision making, orientation, strategy and skill. Furthermore, some scholars like Brannback and Heinonen (2003), Al Natsheh et al. (2013b), and Simmons and Hornsby (2014), suggested that investigating external factors, such as institutions and networks, would provide better knowledge of the process. Therefore, it is important to consider both internal and external factors in the commercialization process. Thus, the second question of this study was developed as follows:

> ***RQ2: What are the commercialization processes and their enablers in high technology industries?***

The third RQ emanated from the suggestion of Rasmussen (2011), Datta et al. (2013) and Pellikka (2014). These scholars recommended that other factors, rather than the above-mentioned factors, must be considered in order to understand the commercialization process. One of the current factors that is affect various activities is digitalization. According to *The Economist* (2012), Schwab (2015), and Parviainen et al. (2017), we are in the digital age, when almost everything is connected by digitalization. These authors stated that our daily activities, working styles, transportation systems and industrial activities are changed with digital technologies. The authors asserted that these situations are a pathway to the fourth industrial revolution, which keeps evolving every day. To buttress the argument of these authors, a desktop research was conducted on digitalization and commercialization process. It was found that little or no work on the topic existed. Therefore, the third question was developed as follows:

> ***RQ3: How does digitalization change the commercialization process of high technologies?***

Notably, in this doctoral thesis digitalization refers to the application of digital technologies to different spheres of the commercialization process. This definition is in line with the description by Brennen and Kreiss (2016), Parviainen et al.

(2017) and Gbadegeshin (2019b). These scholars state that digitalization is an application of ICT technologies to different human activities.

In summary, RQ1 is an eye-opener for the study. It inquires about problems that commercializers might be facing in order to have a better understanding of the commercialization process. This RQ also inquires how the process could be improved. As RQ1 opened the door for new insights to emerge, RQ2 seems to deepen that insight by investigating the entire commercialization process and inquiring about how the commercialization process is done in the selected industries. It also inquires about how different factors facilitate or hinder the commercialization process of these industries. Furthermore, RQ3 provides more insight into the commercialization process. It examines how the current digitalization situation changes the process. It seeks to outline changes in the commercialization process due to digitalization.

1.3 Relationship among Objectives, Research Questions and Articles of the Study

The research questions were addressed through four articles to achieve this study's goal. The first article focused on the challenges facing the commercialization of high technology by drawing on a case study of Quantum Key Distribution (QKD) technology. QKD belongs to Cybersecurity, which is part of the ICT industry. This case study comprised key stakeholders of the sector across European Union countries. The article identified more challenges in additional to the general and specific industrial problems associated with the commercialization processes. The second article examined the commercialization process of a Cleantech high technology over a three-year period (2013-2016). The article used a case study of a Cleantech company (Spinoff) and considered all its stakeholders. The article provided in-depth knowledge on the commercialization process, and internal and external factors. The third article investigated the commercialization process of various high technologies from the ICT, Cleantech and Life Sciences industries, using data reported between 2012 and 2017. The article proposed a new theoretical framework termed *Lean commercialization*. The Lean commercialization theoretical framework is flexible, cost effective and efficient, and risk and uncertainty considerate. The last article centered on the commercialization process of high technologies from Life Sciences and digitalization. It researched changes of digitalization on the process. Specifically, the article examined the high technologies from NDD, medical devices, and e-health companies in the industry. All stakeholders of the industry were interviewed, and the article detailed the changes of digitalization on the commercialization process.

Regarding the objectives of the study, the articles investigated the commercialization process of various high technologies from the selected industries. They provided insights on the process, theoretically and practically. Theoretically, the article 3 provided a lean commercialization framework for the high technologies, which has not yet been propounded in the commercialization discourse. Similarly, the article 2 argued that Spinoff is not necessarily based on the stage approach, which supports a mixture of linear and non-linear logic of the current debate on the commercialization. Practically, the article 1 provided information on the possible problems and how these challenges could be managed by entrepreneurs and potential entrepreneurs. Articles 2 and 3 also provided practical advices to the practitioners. Article 4 presents areas of consideration for the companies concerning digitalization. Chapter 5 (section 5.3) presents the details of the contributions of this study.

Furthermore, this study's articles provided answers to the RQs. Article 1 provided answer to RQ 1 by presenting other challenges confronting the high technologies from the ICT industry. Likewise, the article 4 answered RQ 3 by presenting the changes of digitalization on the commercialization process. All the articles provided answers to RQ 2 in terms of problems, processes, and enabling factors. Therefore, the objectives, the RQs and the articles are related. Their relationship is shown in the following Table 1.

Table 1: The Study's Objectives, Research Questions and Articles

Objectives	**Research questions**	**Articles**
To investigate how high technologies are commercialized, especially in ICT, Cleantech and Life Sciences industries.	1: What are the challenges of the high technologies' commercialization process?	1 and 2
	2: What are the commercialization processes and their enablers in high technology industries?	1, 2, 3 and 4
	3: How does digitalization change the commercialization process of high technologies?	2 and 4

However, the articles have some differences. First, their theoretical frameworks are different. Article 2 employed Spinoff and TOT models (which are based on NPD), but the article 3 used lean or agile models (which are related to entrepreneurship creative theories). Likewise, the article 1 was based on a literature overview of commercialization challenges of different industries, but the article 4 was based on commercialization models for Life Sciences industry. Second, the instruments for their data collection are different. Article 1 used interviews and surveys to collect data, while the articles 2 and 3 used observations and interviews. Article 4 used only interviews for its data collection. Third, their study partici-

pants are varied, though these participants are key industry stakeholders. The study participants of articles 1, 2, and 4 represented all stakeholders, including innovators, research institutes, technology transfer officers, incubation centers, business advisors or developers and government agents. Meanwhile, article 3's participants did not represent all stakeholders, but only innovators and business advisors. Fourth, there are differences in the case study high technologies and their companies. Articles 1, 2 and 4 focused on the high technologies from ICT, Cleantech and Life Sciences companies, respectively, but article 3 considered the high technologies across the selected industries. Last, each article has different focus. Article 1 focused on the challenges, while article 4 focused on digitalization. Articles 2 and 3 focused on implementation of commercialization activities, though article 2 concentrated on the entire process; whereas article 3 centered on the approach (lean) of the process.

The differences among the four articles brought diversified views and knowledge to this study. Their differences enabled a broad view for analyzing and understanding the commercialization process, which is essential for developing a flexible and cost-effective commercialization framework. According to Datta et al. (2013), Pellikka (2014), and Lavoie et al. (2017) diversified views are needed in developing the commercialization framework. Their differences also provided deep insight from their empirical approaches, as Djokovic and Souitaris (2008) and Evers et al. (2016) argued. To round off this subsection, the following Table 2 presents important information on the articles of this study.

Table 2: **The Study's Articles**

	Title	Industry & Companies	Research gaps	Empirical data	Findings	RQs
1	Identifying the Challenges in Commercializing High Technology: A Case Study of Quantum Key Distribution Technology	ICT (Metrology institutions and cybersecurity companies)	(i) Insufficient knowledge of challenges facing emerging industries. (ii) Need for case study approach to identify critical challenges.	(i) 4 interviews with innovators / CEOs from metrology institutions (ii) 2 interviews with managerial position holder in QKD technology companies. (iii) 60 responses from online survey of QKD professionals (e.g., professors and researchers)	Identified these problems: (i) Scattered and small markets (ii) Supply chain development, (iii) Technology validation/certification (iv) Lack of available or adequate infrastructure, (v) After-sales services, (vi) technical development, (vii) Customer orientation / awareness, (viii) Government regulations	1,2
2	Commercialization Process of High Technology: A Case Study of University Spin-off	Cleantech (measurement device)	(i) Insufficient empirical and longitudinal studies, (ii)Request to examine stage-gate model.	(i) Analysis of 96 documents, such as commercialization plans, steering group minutes and presentations, periodic reports, NAM website and online news. (ii) 8 Interviews with commercialization team. (iii) 10 interviews with stakeholders, such as potential customers, distributors and government regulatory body.	(i) Commercialization process may not necessarily be stage-based. (ii) Success factors for the university Spinoff commercialization process are - university vision and interest, personal interest and motivation of both innovators and business team members, ability of innovators to identify opportunity and industrial or legal knowledge, working experience of commercialization team, trust and previous positive collaboration of the team -individual network of the team, industrial connection / relationship, good leadership and team commitment. - international networks, creation of awareness and industrial collaboration (iii) Flexibility of the commercialization process (iv)Plan is always a plan	1, 2, 3
3	Lean Commercialization: A New Framework for Commercializing High Technologies	ICT, Cleantech and Life Sciences companies	Lack of commercialization framework for modern technologies	(i) 2 initial interviews (2012) with serial entrepreneurs. (ii) Observation of 25 high tech companies between 2013 and 2016 (iii) 4 retrospective interviews with business advisors.	(i)Application of the lean startup methodology to the commercialization process (ii) Development of the lean commercialization framework	2
4	The Effect of Digitalization on the Commercialization Process of High Technology Companies in the Life Sciences Industry	Life Sciences (NDD, medical device and e-health companies)	(i)insufficient scholarly articles on digitalization (ii) underdeveloped research on relationship between digitalization, comm. process	16 interviews with CEOs/inventors, business development managers, senior business advisors, university innovation managers, and executive director of a government agent for innovation funding.	(i)Differentiating digitization from digitalization. (ii)Digitalization and a new form of commercialization process. (iii)List of digitalization transformations on the commercialization process.	2,3

1.4 Empirical Context of the Study

Contextualization is essential in the studies of the commercialization process. Meanwhile, most of the previous works focused on a specific sector or industry. For example, Maine and Garnsey (2007) worked on advanced materials, McNeil et al. (2007) researched nanotechnology and Pietzsch et al. (2009) examined medical devices. There are some prior works that are not contextualized and seem to be general, for instance, Grönlund et al. (2010), Amadi-Echendu and Rasetlola (2011) and Holzleitner (2015). Nonetheless, the current study investigates ICT, Cleantech and the Life Sciences to provide a better understanding of the commercialization process. This is initially echoed in the work of Pellikka (2014) and Aarikka-Stenroos and Lehtimäki (2014). Besides, contextualization paved the way for an in-depth understanding of a phenomenon as it encouraged Baker and Welter (2018), who state:

> *...if we are fortunate, new interpretations and meanings may start to emerge which allow us to question important taken-for-granted assumptions and judgments that may underlie established theories and concepts. (p.33)*

Therefore, this study is empirically contextualized in the high technology industries. ICT, Cleantech and the Life Sciences were considered. These industries were selected because they are high technology–based industries according to Eurostat (2016) and Aydalot and Keeble (2018). The technologies of these industries are complex, some are tedious, and they require a large R&D investment. Thus, the commercialization process of their technologies is complicated. Therefore, these industries are suitable for in-depth investigation of the high technologies' commercialization process. Besides, the industries play significant roles in modern economies, as Schrier and Hallin (2017) explained, in that their technologies are connected to economic advancement. These industries are important in the study of commercialization. Furthermore, some prior works on commercialization, such as Dogra et al. (2013), Novickis et al. (2016) and Lavoie et al. (2017), used these industries. Each industry is described briefly in the following paragraphs.

ICT Industry. According to the Economic and Social Council (2004), the ICT industry consists of organizations that engage in manufacturing products and offering services associated with information processing and communication. The products and services are expected to have the ability to transmit and display information as well as to use electronics. Similarly, the products and services of the industry are expected to detect, calculate, record and (even) control both physical and non-physical particles, elements and things. The Economic and Social Coun-

cil (2004) concludes that this description: *implies that the ICT sector refers to equipment and services related to broadcasting, computing and telecommunications, all of which capture and display information electronically* (p. 2).

In addition, Eustat (2016) writes that the ICT industry contains any companies and institutions whose products and services are associated with the development, production, commercialization and use of ICT. Eustat (2016) outlines that the manufacture of electronic components, computers and peripheral equipment, telecommunication equipment and devices, consumer electronics, magnetic and optical media, software, cable products and devices and satellite equipment all belong to the ICT industry. Services around the aforementioned products, as well as cable telecommunication, internet, programming, consulting, data processing, hosting, web portal and related activities and repairing and maintenance, also belong to the ICT industry (Eustat, 2016).

In respect to the above descriptions, it can be deduced that the ICT industry does more than manufacture and provide services around phones and computers. It also seems that the industry is huge and is interconnected with other industries. For the purpose of this study, the focus was on the companies dealing with the production of information systems, electronics and optics. These companies were selected because of their important roles in the ICT industry and the application of their products in the Cleantech and Life Sciences industries.

Cleantech Industry. Cleantech is synonymous with *clean technology* and *green technology*. According to Dikeman (of Cleantech Group), this industry entails several organizations, such as companies, venture capitalists, research institutes and government agents, that work on renewable energy (e.g., solar, wind and biofuels), sustainable environment and natural resource maintenance. Dikeman also notes that, due to the wide use of *Cleantech*, experts from the industry summarize that this economic sector is composed of organizations that produce products and services for operational efficiency, better productivity and efficient use of available resources and energy consumption. Dikeman also adds that the organizations that offer products and services for waste and pollution management belong to the industry.

Furthermore, Cleantech Group summarizes the industry as consisting of any product, service, and process that aims to provide better performance with lower costs, reduce or eliminate negative ecology, and improve responsible use of natural resources. They also note that the industry has eleven segments: energy generation, energy storage, energy infrastructure, energy efficiency, transportation, water and wastewater, air and environment, materials, manufacturing, agriculture, and recycling and waste. This is supported by Nauta (2014), who says, *we are now very much in the era of 'Cleantech 2.0,' going far beyond the renewable*

energy focus of 'cleantech 1.0,' to include energy, material and resource efficiency as well as adaptation technology (p. 5).

The Cleantech industry is growing, and its sectorial scope has grown wider than before. Lane (2011) notes that the industry is diversified, but it has a goal. The author also states that the main goal of the industry is to improve the environment and reduce negative climate change through the generation of renewable and sustainable energies, promoting efficiency and minimizing greenhouse emissions.

The above presentations show that the Cleantech industry is beyond the products and services of green technologies. It has also shown that the industry has a relationship with other industries, specifically ICT. Hence, in this study, companies that produce and offer services for measurement and renewable energy technologies were the focus. Notably, many measurement products have medical applications.

Life Sciences. This industry consists of various organizations that deal with medicine, biochemistry, biophysics, pharmacology and neurology, among others. According to Laurell et al. (2013), the industry has pharmaceutical, medical technology and biotechnology sectors. Laurell et al. (2013) explained that the pharmaceutical sector consists of companies and organizations that deal with drug development and marketing. These authors stated that this sector is typically dominated by a few multinational companies. On the other hand, the authors stated that the medical technology contains organizations that produce and offer services pertaining to medical devices and medical supporting services. The authors noted that this sector is usually dominated by small and medium-sized enterprises. The authors explained that the biotechnical organizations make use of living organisms to manufacture products and offer services. The authors added that this sector is also dominated by small enterprises.

The Life Sciences industry is different from other high technology industries with some features. First, it is strictly regulated, as noted by Kaitin (2010) and Khilji et al. (2006). These regulations ensure the safety of human beings and the efficacy of the proposed drugs. Second, the industry is highly science-based and focuses on quality of life. Stremersch and Van Dyck (2009) explained that the Life Sciences seems to be the only industry in which most of its products are services developed from a series of scientific investigations. Third, it is capital- or finance-intensive. McKenzie et al. (2006) and Maak and Wylie (2016) stated that the industry requires huge investments in both R&D activities and even the manufacture of its products and services. Fourth, its R&D process is unique and complex. McKenzie et al. (2006) and Maak and Wylie (2016) also point out that the industry is complicated in its R&D activities. These scholars cite that the process of product *A* is often different from *A1*, which belongs to the same product.

Fifth, there is a global market. According to Stremersch and Van Dyck (2009), this is because its products and services deal with people or living beings. Hence, these scholars concluded that there is always international business for the industry.

In this industry, NDD, the medical device and e-health companies were selected for this study. These companies are key stakeholders in the industry, and they have the most important features of the industry. They were also selected because of their relationship with ICT and Cleantech (specifically, measurement technologies).

Above all, the technologies of these industries are complex, highly innovative, R&D-dependent, and resource-intensive according to Eurostat (2016), Steenhuis and De Bruijn (2006) and Solberg et al. (2008). Thus, they are high technology industries.

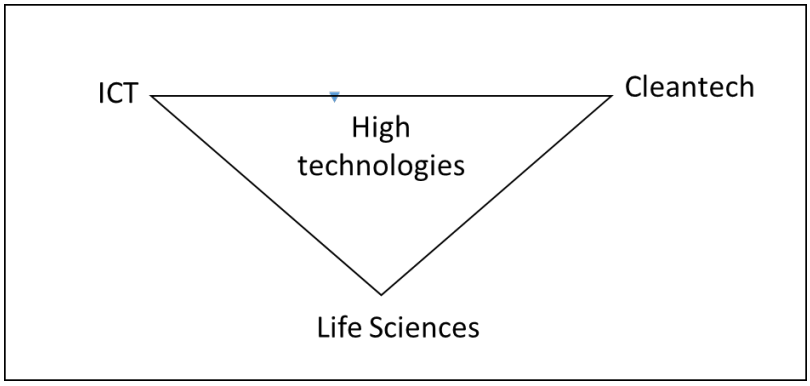


Figure 2: The Empirical Contexts of the Study

1.5 Key Terms of the Study

1.5.1 The Commercialization Process

The commercialization process is regarded as a procedure in which discovery and new ideas are converted into real products and services. The discovery usually develops from the research and development (R&D) activities of organizations like universities, public research centers and private companies (Fontes 2005). It contains steps of research result valorization (Ndonzuau et al. 2002); hence, it is regarded as supply chain management for a new product or service from the point of inception to the point of consumption (Rogers et al. 2004).

The preceding definitions revealed that the process contains several activities that make it complicated to understand. These activities require time-consuming

decisions in some cases. Similarly, the activities are interconnected and span across the different departments of organization. In a nutshell, the commercialization process encompasses all the important steps involved from idea conception to new product or service consumption by the ultimate customers. The steps cut across these functions: product or service designing and planning, marketing, supply chain management, human resource management, financial and accounting management, information technology, and legal and regulatory management (McCoy et al. 2008, 142; Van Norman & Eisenkot 2017).

In this study, the commercialization process denotes any activities that involve transforming new high technologies to become consumable, acceptable, adoptable and re-purchasable by target customers. These activities are expected to vary from one technology to another and from one company or industry to other. Meanwhile, it is expected that the process has some commonalities among high technologies and is flexible so that the uncertainty and complexity of high technologies can be managed effectively and efficiently.

1.5.2 The High Technologies

There is an ambiguity in describing high technologies, because they are associated with economic growth, which is characterized by many factors. As a result, there are many perspectives from which to define high technology, including industry, firm, product and life cycle–based perspectives. According to Steenhuis and De Bruijn (2006), there are two aspects of high technologies that are often considered: complexity and newness. They explained that complexity is stable because high technologies are always complicated, and newness is dynamic because high technologies are often new *things*. The scholars further explained that these aspects are often used to define technological measurement tools, which are identified as process complexity, product complexity and product development rates. These tools are used to categorize different technologies into Low, Low-Medium, Medium-High, and High. Thus, the scholars pinpointed that the high technologies have the highest levels of process complexity, product complexity and product development rate. Additionally, Eurostat (2016) states that high technologies use sophisticated technologies. These technologies are cutting edge and are closely related to advanced technological development and economic growth according to Schrier and Hallin (2017).

Furthermore, the high technologies can be described as a new activity, innovative industry, product and science. An activity is considered as a high technology if it could be a new phenomenon that industries and companies engage in to improve their productivity. Similarly, any industry that is full of innovations or in which innovations play an important role is considered as a high technology.

Likewise, any industry whose new product or service could disrupt people's lives is known as high technology. Most importantly, any technology that is science-based and that highly skilled people are working with is considered as high technology (Aydalot & Keeble 2018).

Given the aforementioned features, high technologies have a high level of uncertainties in terms of market and technology. Their market uncertainty emerges from unexpected responses from customers, while their technology uncertainty comes from technical or engineering challenges. Meanwhile, the high technologies do serve as a source of competitive advantage (Mohr et al. 2005).

In term of industry, high technology industries refer to the industrial sectors which significantly invest in R&D. The high technology industries produce innovative and advanced technical products and often apply the state of the art to their production processes (Wong 1990). These industries have high budgets for their R&D activities, and they focus on the added value of these activities. The industries can be grouped into Low, Low-Medium, Medium-High, and High (Solberg et al. 2008; Eurostat 2016).

Based on the above characteristics, the high technology, in this study, refers to technologies with a high level of R&D, complexity, advanced development and uncertainties. These technologies are developed from science-based institutions or with the support of research institutions and are referred to as the technologies with industrial applications. They are expected to bring added value to the production line (for both goods and services). Moreover, high technology was considered as a technology, product, service, solution, and industry in this study.

Meanwhile, it is essential to differentiate high technology from innovation. This differentiation will facilitate understanding of the commercialization process. Hence, innovation, like high technology, has numerous definitions. Nevertheless, definitions of innovation from the 1990s (e.g., Freeman & Soete 1997; Veryzer 1998) to 2000s (e.g., Ettlie & Subramanian 2004; Galanakis 2006; Robbins & O'Gorman 2014;) show that it involves creation of *something* new. The term *something* is mostly referring to products, services and processes by aforementioned scholars of innovation. Some of these scholars are more specific by including devices, systems, knowledge, procedures, and practices into *something* new, while some of the scholars state that *something* could be new to a firm, an industry or the entire world. However, it is noted that the combination of all these *somethings* new are not clearly articulated by these innovation scholars. Nonetheless, all the scholars affirmed that *something* new, either singly or in combination, should offer value to users and economic benefit for the producers.

The above scholars noted that innovation is not completed until it involves a business transaction. They explained that an innovation must be exchanged between the producers and users such that both of their interests are satisfied. The interest of the producer is economic benefit, while users are interested in having

their needs, wants and preferences satisfied. The scholars emphasized on the acceptance by the market is crucial for any innovation. Additionally, some scholars such as Kotsemir and Meissner (2013) and Anderson et al. (2014) elucidated that invention and creativity are a part of innovation activities. Similarly, Crossan and Apaydin (2010) claimed that innovation can be leadership, process and outcome. Therefore, it can be deduced that innovation consists of creativity and inventions that lead to the creation of new *solutions* that offer *value* to both creator and users. Furthermore, these solutions must be acceptable to the users. In other words, innovation is a commercialized idea (or invention).

While debating about the newness of solutions, most of the above-mentioned scholars classified innovations into radical, incremental, architectural, sustainable and disruptive. It is noted from the debates that these classifications center on three criteria: extent of newness, continuous of newness, and impact of newness. The scholars who explained radical, incremental and disruptive innovations focused on the extent of newness. In this sense, radical and disruptive innovations have the highest newness; whereas incremental has low or moderate newness. This could be the reason that the scholars gave radical and disruptive innovations names like *really-new* and *breakthrough* (see: Rice et al. 2002; Garcia & Calantone 2002). Regarding continuous, the above scholars regarded radical, architectural and disruptive innovations to be discontinuous due to their revolutionary nature, while incremental innovations are continuous. Hence, Lynn et al. (1996) and Veryzer (1998) termed radical, architectural and disruptive innovations as *discontinuous*, r*evolutionary* and *expanding boundary*. Regarding the impact of newness, radical and disruptive innovations have more impact on the companies, industries, national economics and even, the entire world, but incremental innovations have a limited impact. This might be the reason the scholars, such as Coviello and Joseph (2012), called radical and disruptive innovation *major innovation* and *game-changing*. To buttress the differences among different innovations, Veryzer (1998) employed technological and product capabilities to group innovations, and Barbieri and Alvares (2016) used technology and business model to differentiate innovations. Their groupings resemble the previously discussed classification. From these debates, it is deduced that an innovation's features would determine its classification.

Talking about the features, Freeman and Soete (1997), Ettlie and Subramanian (2004) and Galanakis (2006) outlined that a radical and disruptive innovation has a high level of R&D, creativity and invention, contains serious uncertainties, is risky and costly, and has a discontinuous impact on technologies, markets, organizations, industries and resources. According to Rice et al. (2002) and Garcia and Calantone (2002), radical and disruptive innovations could lead to changes in existing infrastructures and sometimes could disturb existing ecosystems. In respect to these features and the above-mentioned characteristics of high technolo-

gy, it can be argued that radical and disruptive innovations are behind high technologies.

1.5.3 Digitalization

Digitalization is highly associated with ICT. This makes the term to be referred to as digitization; however, digitalization differs from digitization. According to Brennen and Kreiss (2016), digitalization is a structure of digital technologies to various dimensions. The dimensions include infrastructural, device, functional and rhetorical, and market convergences. The infrastructural convergence refers to the combination and utilization of various infrastructures with the help of digital technologies. Device convergence is the availability of devices that encompass other devices; for example, Smartphones can serve as phones, computers, cameras, and so on. The functional dimension entails a network of devices and infrastructure. The implication or effect of functional convergence leads to change in culture in relation to people's lifestyles, organization culture and community culture. Of course, these changes and combinations lead to market convergences in which digital technologies create new and different market systems.

Conversely, digitization is a process of changing analogue data into digital forms. Furthermore, digitalization is described as the application of ICT technologies to business processes, organization activities, industrial development and even to economic and social spheres (Degryse 2016; Parviainen et al. 2017). Additionally, Gbadegeshin (2019b) buttresses that:

> *Digitalization is more comprehensive than digitization and it refers to the application of any digital technologies to any human activities, such as personal life, social, economic, and political activities. Meanwhile, digitization is one of the processes of digitalization that converts analogue inputs to digital outputs. Therefore, the difference between the terms is that digitization is a process of the digitalization phenomenon (p.55)*

Based on scholarly works by Brennen and Kreiss (2016) and Degryse (2016), as well as on reports from the practitioners (e.g., *The Economist* 2012; Schwab 2015), it is observed that digitalization is different from digitization via its technologies. Hence, Brennen and Kreiss (2016) and Degryse (2016) state that digitalization technologies include the Internet, robots, the Internet of Things, automation, big data, artificial intelligence (AI), 3D printing, autonomous vehicles, cyber weapons, drones, surveillance and quantum computing. Similarly, technologies relating to nanotechnology, biotechnology, and material sciences are regarded as digitalization technologies. Additionally, Gbadegeshin (2019a) adds that

technologies relating to blockchain, smartness (e.g., smart cities, smart grids), computing (e.g., social computing, cloud computing, expert systems, agents and multi-agent systems), information processes (e.g., natural language processing, image processing and data mining and analysis), e-platforms (e.g., e-learning, e-business, digital marketing and virtual organization), augmented reality, virtual reality, satellite communication systems, 5G network evolutions and biometrics, are all digitalization technologies. Therefore, this study defines digitalization as the application of those technologies to commercialization activities.

1.6 Structure of the Study

The study is divided into two sections. The first section presents a synthesis of the study; the second section presents the original articles. This is Chapter 1 of the first section, and it explains the study's background, scope, objectives, research questions, contexts and key terms. The remaining chapters of the first section are described briefly below:

Chapter 2 presents the study's theoretical background. It discusses the theories, theoretical frameworks and models of innovation, NPD, entrepreneurship, Spinoff, TOT and marketing fields. Furthermore, the chapter also presents summaries of the commercialization process models from the selected industries.

Chapter 3 presents the study's entire research process: its research method, instruments and process. It also describes the study's participants, and it discusses the study's validity and reliability.

Chapter 4 presents an overview of the study's articles. It explains each article's goals, research questions, research method and instruments, findings and contributions.

Chapter 5 is the discussion and conclusion. It presents the main findings of the study and answers the RQs, as well as the discussion and theoretical contributions of the study. Practical implications, limitations and suggestions for future studies are also given. This chapter is accompanied by references and the original articles used in the study that represents section 2.

2 THEORETICAL BACKGROUND OF THE STUDY

Establishing a sustainable business is one of the primary objectives of commercialization (Ulrich & Eppinger 2011; Kahn et al. 2013; Al Natsheh et al. 2015). This objective has a close relationship to the aims of innovation, new product development (NPD), Spinoffs, transfer of technology (TOT) and entrepreneurship processes. Thus, this study considered the commercialization process as a business process. In view of this, the Business Platform model developed by Klofsten (2010) stated that high technology-based companies often emerge from an innovation. The model details that such innovation passes through several phases in which a new business is born and nurtured. Additionally, the model's pillars are idea, product, market, organizational development, core group expertise, prime mover and commitment, customer relations and firm relations. Management of these pillars determines the growth and sustainability of any high technology-based company. All the pillars reflect core concepts and activities of selected fields. Therefore, this study employed the theories, theoretical frameworks and models from these disciplines. These fields have numerous studies on the commercialization that have impacted the discourse on the commercialization process. This chapter discusses some of their theories, theoretical frameworks and models. Similarly, the chapter discusses commercialization models from the contextual industries.

2.1 The Theories and Theoretical Frameworks of Selected Fields

As stated earlier, this study employed the theories, theoretical frameworks and models of six selected fields, which could be used to provide a theoretical understanding of the commercialization process according to Pellikka (2014). Similarly, it was noted that the literary works on the commercialization have developed from these fields. Thus, this section presents the key theories of some disciplines and discusses various theoretical frameworks and models of the fields and discusses key commercialization process models from the empirical industrial context.

2.1.1 Innovation Process Theory

Innovation process theory is the foremost theory associated with the commercialization process. The primary reasons are that the commercialization process is part of the innovation process, high technologies make use of radical innovations, and the other fields, such as NPD, TOT and Spinoff, are like branches of the innovation process theory. Meanwhile, to have better understanding of any theory, it is essential to consider its historical development. Thus, the theories and theoretical frameworks associated with the innovation process have been traced back to the 1950s after World War II. It is learned from the previous works, Rothwell (1994), Buijs (2003), and Barbieri and Alvares (2016), that these theories have generations. It was noted that these generations are termed differently by the different scholars of innovation process theory, but their theoretical assumptions are the same. For instance, Barbieri and Alvares (2016) noted that the coupling model is alternatively named as interactive, a combination of the technology push and market pull model and portfolio management. Meanwhile, these generations generally consist of technology push, market pull, coupling, interactive, integrated, networking, open innovation and open innovator. The first five generations are confirmed by several scholars, such as Kotsemir and Meissner (2013) and Barbieri and Alvares (2016), who conducted literature reviews on the innovation process. However, the last two generations appear to be evolving, because many scholars are still working on them. For examples Marinova and Phillimore (2003), Chesbrough (2003), and Bochm and Frederick (2010) are working on the sixth generation. Although the works on the sixth generation have differences, they concentrate on networking, open innovation and the combination of several knowledge bases or competencies from inside and outside an organization. Notably, the work of Barbieri and Alvares (2016) adds incremental innovation to the discourse of the sixth generation.

Each generation seemed to be affected by the prevailing economic and technological factors. For instance, technology pull theories reigned between 1950s and 1960s, because there was an industrial revolution and technology developments during that time. Similarly, networking theory prevailed in the 1990s, because information technologies emerged during that period. Open innovation and innovation are currently gaining ground due to the influences of internationalization, globalization and digitalization, according to Gassmann (2006) and Barbieri and Alvares (2016). These factors and others, such as social and environmental factors, are expected to influence innovation process theories because they are not controllable, and innovations depend on them to emerge. This could be the reason for Galanakis (2006) adding external business factors and national innovation ecosystem into the theoretical framework of the innovation process.

All generations of innovation process theory have some differences and commonalities. Their differences are basically related to economic and external factors, sources of innovation and implementation of the innovation process. The external business environment factors, such as economic, political, technological, legal and social, seem to determine the possible theoretical assumptions of the generation models. For example, in the 1950s and 1960s, economies needed new technologies to improve existing industries and to create new ones. The emergence of the third industrial revolution compelled the development of new technologies. This situation caused universities and industries to develop new technologies from research. Thus, the innovation implementation process was linear; that is, from research to development to manufacturing and marketing. Therefore, the first generation theoretical frameworks are linear or technology-pull. In contrast, internationalization, globalization and information technologies were prevalent in the 1990s and 2000s. The market orientation and need of customers became paramount for new technology development, and parallelization of the innovation process was possible with strategic collaboration with supply chain members. The implementation of the innovation process was not directly linear but simultaneous. These situations led to market pull, coupling and integrative generation models.

The similarities of the aforementioned generations relate to the origin of innovation, the type of innovation, the nature of the end result of innovation, the role of the market, characteristics of innovation, phases of the process, commercialization, and the type of industries. For the origin of innovation, Barbieri and Alvares (2016) explain that:

> *There is no innovation which does not originate from one or more ideas. This is present in all the innovation models mentioned. There is no other reason that the sources of ideas for innovation are central themes of innovation management in all good books and articles on the subject. That which comes to be a good idea presents different understandings as per that in relation to radical or incremental innovations. (p. 120)*

For the type of innovation, all generation theoretical frameworks focused more on radical innovation than on incremental. This focus prompted the sixth generation model of Barbieri and Alvares (2016). For the nature of the end result, all generations of the innovation theory focused on products or processes more than services or systems. This is noted by Barras (1986) and, since then, fewer works discuss services or systems (nowadays known as solutions). For the roles of market, all the theories agreed that the market plays a significant role in the innovation process and determines the success or failure of the entire process. Similarly, all the theories affirmed that, regardless of the type, innovation often entails un-

certainty, complexity, cost, risk, resources, and competencies. For the phases of the process, all the models showed that there are development, manufacturing and commercialization phases. Last, all theoretical frameworks of innovation process are developed from case studies of high technologies or industries such as pharmaceutical, aircraft, automobile, semiconductors, material sciences, and electronics.

From the preceding, it can be deduced that different generation models are linked and are still employed by various industries in combination. Similarly, it can be deduced that both linear and non-linear logics are mixed in the theories. These are noted by Rothwell (1994) and, more recently, from Cooper (2008, 2014) and Gbadegeshin (2018a, 2019b). However, if the external factors are critically considered, the old generation theories might not be suitable to present situations. Presently, globalization (facing challenge with nationalism), digitalization, multicompetences of labor and other factors of the fourth industrial development are becoming realties. Additionally, there are many sources of innovation in which universities (including research centers) and industries are a part but not the sole source. Likewise, implementation of innovation is becoming simultaneous, flexible, cost and resource conscious, and timely. Even the recent generation frameworks, such as fifth and sixth models, seem to be constrained due to lack of entrepreneurship roles in the process. Furthermore, *solutions* as part of the end results of innovation need to be considered. Solutions or combinations of products and supported services seemed to be ignored in previous models. Therefore, a need exists for an up-to-date innovation process theory, especially in relation to the commercialization process of high technologies. Figure 3 presents an overview of the innovation process framework.

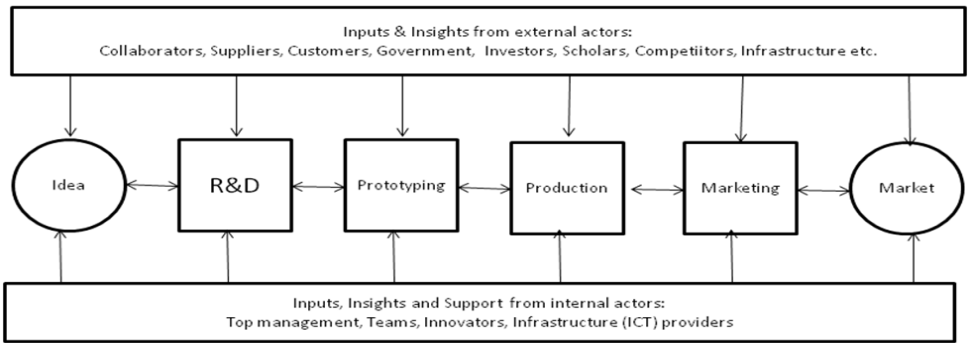


Figure 3: An Overview of the Innovation Process Framework

Apart from the above discussion on the innovation theories, it is learned that the theories and their theoretical frameworks are discussed from two standpoints – the conceptual and practical viewpoints. The conceptual approach expatiates on

how innovation processes are performed abstractly and provides analysis of certain assumptions and conditions for theoretical frameworks and models. Conversely, the practical approach examines the innovation process from socioeconomic environments by focusing on firm, industry and national or multinational levels of analysis. These standpoints are also noted by Kotsemir and Meissner (2013). The conceptual school developed their theoretical assumptions from various theories associated with the management, economic and social sciences. Specifically, the practical school employed theories of marketing, operation management, strategy and strategic management, economics and organization development, according to Loch and Kavadias (2007). Notably, most of the theoretical frameworks and models from the practical school of thought are closely related to or interchangeably referring to NPD. Nevertheless, both standpoints regard commercialization as the last step of the innovation process. This is surprising, because all the definitions given to the innovation process (see: Crossan & Apaydin 2010; Kotsemir & Meissner 2013; Anderson et al 2014) emphasize that commercializing an invention is known as innovation. In fact, Rothwell (1992b; 221) stated, *the process by which technology is commercialised is [the] innovation process*.

In respect to the assertion that commercialization is the final stage of the innovation process, the above-listed previous works treat commercialization as marketing, sales, product launch and distribution. Some theoretical frameworks, especially from the conceptual approach (e.g., Rice & Roger 1980; Salerno et al. 2015) termed it as diffusion or adoption of new technologies. Consequently, there are theories or theoretical frameworks developed for diffusion and adoption as the final part of the innovation process. According to Rogers (2003) and Hoffmann (2011), diffusion is described as a process of the communicating values of innovation to adopters over a period. It consists of innovation, communication channel, time and adopter (someone who is a member of a social system). Thus, the diffusion process comprises (1) possessing knowledge on the innovation, (2) persuading adopters to accept the innovation, (3) users deciding to accept or reject the innovation, (4) adopters implementing the innovation, and (5) confirmation of the innovation. Similarly, and according to the same scholars, adoption is a process of accepting or rejecting innovation. Thus, adoption is a part of the diffusion process. The relative advantage (values), compatibility, complexity, trialability and observability of the innovation (Hoffmann, 2011; 37) would determine its adoption. The adopters are categorized as innovator, early adopter, early majority, late majority and laggards. *Innovator* in the adoption sense refers to the first buyers of an innovation; they are regarded as innovators because of their *venturesome* personality. It can be noted that diffusion and adoption are interconnected, as Straub (2009) stated:

> *Adoption-diffusion theories refer to the process involving the spread of a new idea over time. The adoption process refers to the individual's decision whether to integrate an innovation into his or her life; diffusion describes a collective adoption process over time. Adoption-diffusion theories share several characteristics… (p. 629)*

Straub (2009) pinpointed that the diffusion theory deals with the macro perspective of making an innovation acceptable, whereas adoption theory deals with the micro perspective of adopting, adapting or rejecting an innovation (p. 626). It is observed that both theories originate from the work of Rogers (1962). A critical synthesis of both theories from the original work and subsequent discussions from Rogers (1995, 2003), Venkatesh et al. (2003) and Straub (2009) suggests that the theoretical assumptions of both theories are (1) there is an innovation that needs to be diffused to a certain group of users, (2) information on the innovation needs to be spread via different means of communication and must contain relevant details of the innovation, (3) the target user group is assumed to receive the information, analyze it and decide, (4) the user's decision takes a long of time, (5) the decision to adopt an innovation shows changes in user behavior, and (6) there are many factors, at individual and society levels, that affect users' decision.

Other theoretical frameworks for the adoption-diffusion (as named by Straub 2009) of new technologies or innovations are the Technology Acceptance Model (TAM) and Universal Technology Adoption and Use Theory (UTAUT). These theories are commonly discussed and tested models. They represent the commercialization part of the innovation process. TAM was developed by Davis (1989) in relation to social cognitive theory and decision-making theories. TAM assumes that perceived features of an innovation would either enhance or hinder its adoption by the user. Thus, TAM has two theoretical assumptions: a technology's perceived ease of use and perceived usefulness determines its acceptance. Additionally, perceived ease of use is described as self-efficacy of the user. TAM is criticized by scholars, such as Venkatesh et al. (2003) and Straub (2009). The main criticisms are that self-efficacy is not associated with perceived ease of use, the absence of individual differences, and two features of innovation cannot solemnly determine technology adoption. The critics add that personal traits which consist of gender, age, education level and exposure, previous experience and others are not considered in the framework; meanwhile, these traits have an impact on technology acceptance.

Due to the above-stated flaws of TAM, Venkatesh et al. (2003) developed UTAUT. This model was developed from eight previous and associated frameworks of technology acceptance. Among the previous frameworks are the Theory of Reasoned Action, the Theory of Planned Behavior, the Motivation Model, the

Innovation Diffusion Theory (the same with adoption-diffusion) and TAM. UTAUT assumes that there are key determinants and moderators for accepting new technologies. The key determinants are performance expectancy, effort expectancy, social influence, and facilitating conditions. Similarly, moderators are personal characteristics consisting of gender, age, experience and voluntariness of use. This theory is currently tested with many empirical studies from various fields of studies. According to Williams et al. (2015), more than 100 academic papers have empirically tested the model, although most of these works are quantitative-based studies. For instances, Straub (2009) tested it on education, De Sena Abrahao et al. (2016) tested it on mobile payment systems, and Olaleye et al. (2018) tested it on a retailing mobile phone application.

2.1.2 New Product Development Process Theoretical Frameworks

Apart from the fact that NPD is derived from the innovation process theories, its theoretical frameworks are quite similar to that of the commercialization process models. The work of Pietzsch et al. (2009) and Grönlund et al. (2010) showed that NPD and commercialization models are closely related. Therefore, considering NPD theory for this study is imperative. Surprisingly, Loch and Kavadias (2007) state that there is no theory for NPD, but these scholars do agree that NPD derives theoretical foundations from economics and management theories. Thus, there are some theoretical frameworks for NPD. Meanwhile, it is noted that these frameworks are practice oriented and belong to the practical school of thought of the innovation process. In short, the NPD process is a management of innovation process. In respect to this view, several scholarly works which include Cooper (1990). Frishammar et al. (2016) and Pereira et al. (2017), consider pre- and post-innovation activities for NPD. Similarly, a large amount of academic studies worked on theoretical frameworks for the NPD process, and many scholars considered different perspectives for the process.

For the pre-innovation studies, the scholars, Robbins and O'Gorman (2014), Frishammar et al. (2016) and Pereira et al. (2017), termed the processes and activities associated with pre-innovation as Fuzzy Front End (FFE) or Front End of Innovation (FEI). The main discussion of these scholars on FFE is that this process contains development, conceptualization and implementation of ideas. The works of these scholars affirmed that the FFE development phase focuses on a *new thing,* which could be an idea or discovery or process of generating them. The scholars agreed that conceptualization refers to attestation or concretization of the idea or discovery. These scholars describe the last stage as execution of a concrete idea or a discovery. However, Perry-Smith and Mannucci (2015) noted that these phases could be prolonged to four phases due to the roles of social

networks, which are significant for the pre-innovation process. The fourth phase, in between conceptualization and implementation, is championing. This phase refers to ranking the best ideas or discoveries during or after concretization. Succinctly, the pre-innovation scholars, Calantone and di Benedetto (1988) and Veryzer (1998), explained that NPD starts from an idea and ends at consumption of the idea as a product or service. This explanation seems to be the underpinning assumption of NPD theoretical frameworks. Meanwhile, it is noted that the NPD scholars often change their focus on FFE, especially when they are trying to propose better and understandable practices and theoretical frameworks for the NPD process.

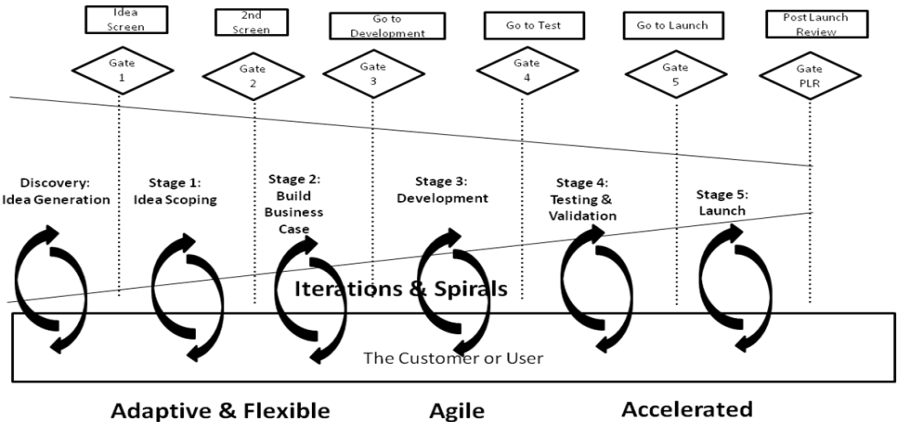
Many scholars, such as Calantone and di Benedetto (1988) and Veryzer (1998), regarded post-innovation studies as the commercialization phase. It is discussed as a last stage of the NPD process, and its discussion is almost the same as what scholars have explained about the innovation process. Hence, the theory of diffusion, TAM and UTAUT theoretical framework are presented by the post-innovation studies scholars such as Rogers (1995, 2003), Venkatesh et al. (2003) and Straub (2009).

For the NPD theoretical frameworks, the most discussed, tested and referenced model is propounded by Cooper (1979, 1980, 1990, 2008, 2014, 2016 and 2017). This theoretical framework emerged from finding solutions to new product failures. The theorist tried to provide practical advice to companies. With his experience and passion for better NPD, he propounded Stage-gate systems in his work (Cooper, 1990). This theoretical framework details the NPD process as idea, preliminary assessments, detailed investigation or business case preparation, development, testing and validation, full production and market launch. The theorist made it clear that NPD starts from an idea, which passes through different gates and stages. The gates are meant for screening, quality control and decision making for continuity or discontinuity of the idea, while the stages are periods when ideas are being processed for the gates. The theoretical framework is redefined in his recent work (Cooper, 2008, 2014, 2017) to inculcate technological changes and challenges. The theorist is presently making the new theoretical frame flexible and adaptive to various changes.

The works of Cooper ((1979, 1980) are modified by prominent scholars such as Calantone and di Benedetto (1988) and Veryzer (1998). Calantone and di Benedetto (1988) noted that NPD can be grouped into three type of activities: technical, evaluation and marketing. According to these scholars, technical activities denote the pre-innovation process, while marketing denotes the commercialization process. These scholars argued that in between the technical and marketing activities, evaluations are occurring. Furthermore, Veryzer (1998) modified the NPD process by integrating pre-innovation activities termed dynamic drifts and convergence. This scholar stated that dynamic drift refers to R&D activities and

their drivers of innovation (which can come from regulations, demographics and economic pressures). The scholar also explained that convergence refers to the opportunity identification of the R&D results. The scholar explained further that convergences are supported by visionary and contextual factors. For the visionary, the scholar stated that this entails individuals or a group of people who envisage technology and market opportunities. For the contextual factors, the scholar outlined that these consist of any issues relating to the application of R&D results, such as existing technologies, company competence, supply chain activities, and even business environmental factors. The scholar explained that these convergences shape the rest of the NPD process, which include formulation, preliminary design, formative prototype and lead-user testing. Meanwhile, the scholar added that there might be several testing activities before final product launch.

Juxtaposing the preceding main theoretical framework of NPD and its subsequent ones, it can be deduced that the theoretical assumptions of NPD are (1) any new product emerges from an idea, (2) the idea needs to be examined at various phases to ensure that its purpose is attained, (3) several factors must be considered during the phases, (4) the process is not *that* linear, but there are various *bus stops* and (5) the user of the new product is important and must be focused on. These assumptions are similar to the fundamental elements of NPD proposed by Loch and Kavadias (2007) – generation, selection, transformation and coordination processes. These scholars explained that the generation element demands that the NPD process should be able to identify new ideas or technologies or market opportunities or combinations of these that can offer commercial value. The scholars also explained that the selection element states that the NPD theoretical frame should be able to define criteria to analyze and rank various ideas or their combination in relation to resources. The scholars added that the NPD theoretical framework should be to show how selected ideas are converted to products and services with economic values. The scholars concluded that the NPD model should reveal how all of those processes are planned, implemented and controlled. Figure 3 shows the theoretical framework.



(Adapted from Cooper 2014; 21)

Figure 4: The NPD Framework

The preceding analysis of NPD theoretical frameworks showed that they employed linear logic, though a new version of the theoretical frameworks appeared to apply a mixture of linear and non-linear logics. Generally, the NPD framework is widely employed. This made several scholarly works consider various aspects of NPD, especially how they affected the process. Examples of aspects investigated by the scholars are the product life cycle (e.g., Oh et al. 2015), customer co-creation or co-development (e.g., Nambisan 2002; Athaide et al. 2003, Hoyer et al. 2010), complexity and adaptability (McCarthy et al. 2006), roles of knowledge (e. g. Carlile, 2002; Smith, et al. 2005), supply chain management (e.g., Langerak & Hutlink, 2008; Oh et al. 2015), strategy (e.g., Ettlie & Subramanian, 2004; Nicholas et al. 2011), roles of collaborators (Rothaermel & Deeds, 2004; Snow et al. 2010), cognitive mapping (e.g., Carbonara & Scozzi 2006), time-to-market or time pressure (e.g., Prasnikar & Skerlj 2006; Kach et al. 2012), market orientation (Im & Workman 2004; Søndergaard, 2005), marketing-manufacturing integration (Song & Swink, 2009) and ICT (e.g., Ozer, 2003; Durmusoglu & Barczak. 2011). These aspects are important to NPD, and these scholars made contributions. Besides these numerous works on NPD, it is learned that the scholars have not yet considered the commercialization process as a part of the NPD process.

2.1.3 Entrepreneurship Process Theories

As it mentioned earlier, the Entrepreneurship process considers the commercialization process as shown in the work of Keskin et al. (2013). Likewise, it mentioned that innovation process theory lacks entrepreneurship despite the fact that innovation serves as a backbone of entrepreneurship. These conditions make the

theory of entrepreneurship essential for a synthesis of the commercialization process. Not surprisingly, there are many theories for entrepreneurship. Its theories also have generations, but this study does not consider them. When previous studies on entrepreneurship were reviewed, it was found that entrepreneurship theories focus on different aspects. According to Kruger (2004) and Ricketts (2008), most of the theories explained venture creation, opportunity exploitation, venture growth and profit maximization. Similarly, Ricketts (2008) noted that many of the theories derived their meta-theoretical assumptions from classical and neoclassical economic theories. Thus, the different focuses of the theories, their different theoretical assumptions and economic changes, make entrepreneurship theories complex and complicated, as Virtanen (1997) and Steyaert (2007) claimed. The review of previous shows that opportunity exploitation seemed to be a popular aspect of entrepreneurship, for which many theories were developed. The scholar, Kruger (2004), elucidated that opportunity exploitation attracted scholars because this is the only area that deals with the entrepreneurship process. Kruger (2004) elucidates further that this area shows links between wealth creation and entrepreneurship.

Steyaert (2007) classified theories on the entrepreneurship process into three different views – the creative process, the discovery process, and the evolutionary process. The creative process view explains that entrepreneurial processes are dynamic and can be attended to innovatively. The theories, from this view, state that entrepreneurial acts are not static, and many methods exist that can be easily applied to exploit different opportunities (Steyaert 2007; Read et al. 2009). Examples of creative process theories are Bricolage, Effectuation and, more recently, Lean start-up. In contrast, the discovery view states that the entrepreneur process consists of efforts to discover opportunities and utilize them. One of this views' prominent theories is propounded by Shane and Venkataraman (2000). The evolutionary view sees the entrepreneurship process as emerging activities that contain risk taking and opportunity exploitation. This view is made famous from the work of Aldrich (1999).

Considering the features of high technologies, which are the focus of this study, the creative process seems to be the appropriate perspective; therefore, this study considers the Bricolage, Effectuation and Lean Start-up theories. These theories have been applied to technology commercialization, and several empirical studies support their application in business contexts. For examples, Garud and Karnøe (2003), Baker and Nelson (2005), and Baker (2007) applied Bricolage, while Read et al. (2009), Berends et al. (2014) and Chandler et al. (2011) used Effectuation in their studies. Similarly, Moogk (2012), Gaffney et al. (2014) and Gbadegeshin and Heinonen (2016) investigated Lean Start-up. The following paragraphs briefly describe these theories.

First, ***Bricolage;*** this theory originates from the work of Lévi-Strauss (1966). Its principle focuses on the creation of some new *thing* from few available resources or on creating new thing by improvising any available resources. Its principle also states that developing new thing by combining different and limited resources. The theory is popularized by *making do*, *improvisation*, *co-development*, and *re-use or combining of resources*. The theory was used in entrepreneurship studies to investigate technology development (e.g., Garud & Karnøe 2003), social value creation (e.g., Johannisson & Olaison, 2007; Di Domenico et al. 2010; Salunke et al. 2013), and entrepreneurship behavior (e.g., Fisher, 2012). Recently, Gbadegeshin (2018b) claimed that when the theory was used in entrepreneurship research, it examined how entrepreneurs make do with what they have at hand, how they recombine resources for new purposes, how they improve their resources, and how they make use of redundant resources to solve problems. Furthermore, the key assumptions of the theory are that entrepreneurs make do with any available resource, recombine or re-use any available resource, and combine any available tools. Drawing on the work of Baker and Nelson (2005), Duymedjian and Rüling (2010) and Fisher (2012)), the above assumptions make the Bricolage process, in relation to the entrepreneurship approach, follow this pattern: business environment → resources → Bricolage (use one or more of the above assumptions) → entrepreneurial activities → new businesses.

Second, ***Effectuation;*** this theory was developed from the work of Sarasvathy (2001) and it is based on the work of entrepreneurship legendary theorist, Knight (1921). The theory states that a new business can be created when entrepreneurs collaborate with their partners to co-create solutions or added value for customers. Its principles are design, means, partnership, affordable loss and leverage contingency. The principle of Design states that entrepreneurs see a future that consists of contingent actions. The principle of Means denotes that entrepreneurs make decisions to utilize new business opportunities by evaluation themselves on what they know, who they are, and the people they know. The partnership principle explains that entrepreneurs create their markets with supply chain players like suppliers, customers, and competitors. This principle emphasizes co-creation. The affordable loss principle means that entrepreneurs are aware of the risks involved in their new business, and they invest only money that cannot affect them negatively if the new business fails. Leverage contingency, the last principle, states that entrepreneurs should be ready to witness surprises: These surprises should be leveraged and turned into new opportunities. In other words, the leverage contingency principle expects entrepreneurs to convert unexpected problems into new opportunities. In a nutshell, the theory asserts that the future can be controlled instead of predicting it. Thus, uncertainty is realistic in the business environment in which entrepreneurs are expected to operate, as noted by

Read et al. (2009), Chandler et al. (2011) and Fisher (2012) when explaining the theory.

Effectuation theory was developed in comparison to Causation theory. Hence, *Causation processes take a particular effect as given and focus on selecting between means to create that effect. Effectuation processes take a set of means as given and focus on selecting between possible effects that can be created with that set of means* (p. 245). Illustratively, chefs provide menus for their customers and produce food according to the customers' preferred or selected menu choices. This is a causation process. Meanwhile, when a chef makes food for the customer with any available ingredients or food materials, the chef employs an effectuation approach (Sarasvathy, 2001). Thus, the Effectuation theory process proceeds from self-evaluation to being one's best to collaboration with others to gaining commitment from partners, and to new means, surprises or business. If new means are created, entrepreneurs return to their competences to utilize the available resources. If a new surprise is developed, entrepreneurs start again from self-evaluation, because the surprise needs to be converted into an opportunity. Similarly, if a new business is created, surprises are expected, and the effectual process starts over again. The Effectuation entrepreneurial process seems to be circular or continuous (Fisher 2012; Berends et al. 2014).

Third, ***Lean Start-up***: this theory is propounded by Ries (2011). This theory's primary principles are that entrepreneurs are everywhere, entrepreneurship is part of management, validated learning is important, innovation accounting is essential, and business can be developed by following the build-measure-learn loop. The theory aims to ensure efficiency and effectiveness, minimize waste and produce acceptable products and services. It focuses on a failing fast and learning more ideology. It also focuses on verification of business ideas or innovation, as well as developing a business model. Thus, the theory asserts a belief in experimentation. It differentiates itself from traditional business development approaches. It is different from others in respect to strategy, new product development methodology, organization structure, and operation perspectives. Strategically, the theory does not emphasize on developing and implementation of business plans; instead, it concentrates on developing a suitable business model for new businesses or existing enterprises. Methodologically, the theory focuses on development of customers and markets, while developing a product suitable for them. Structurally, the theory employs a flexible and flat organization structure and appreciates agile teams instead of standard management. Operationally, the theory makes use of metrics, accepts failure and appreciates customer feedback. Based on the work Ries (2011) and his associates, such as Maurya (2012), Moogk (2012), Blank (2013), and Blank et al. (2013), the entrepreneurial process of the theory is as follows: Idea – developing of Minimum Viable Product

(MVP) – testing of MVP – analyzing and acting upon on test result – decide (to redo, stop or continue).

The aforementioned theories show that the entrepreneurship process starts when an opportunity is noted (recognized). This might be the reason for much scholarly discussion on the discovery or creation of opportunity. This study does not consider this discussion. Meanwhile, the assumptions that an opportunity is both discovered and created are considered as asserted by Ardichvili et al. (2003), Alvarez and Barney (2007) and Davidsson (2015). Similarly, the previously mentioned theories show that exploitation of a recognized opportunity is the next step. The theories reveal further that several activities must be performed in opportunity exploitation, such as personal, resource and environment analyses. Additionally, these theories show that creation and conducting business activities is the third step. Examples of the third step are developing a product or service sample, testing and validating the samples, establishing the business entity and marketization of a validated product or service. This third step employs different methodologies or logics, such as Bricolage, Effectuation and Lean start-up. These logics seem to focus on *little input, but meaningful output*. In other words, these logics enable entrepreneurs to employ few resources, while aiming to offer a meaningful product or service for mass marketing. Furthermore, these theories explain that business improvement is the last step. The theories seem to expect the entrepreneurs to water their newly planted businesses so that those businesses can be sustainable and long lived. The next figure shows these steps. It is conclusively deduced from these theories that they employ non-linear logic. They assume that the business process should be iterative and that external factors influence the business's internal factors. However, these theories do not consider the commercialization process as part of business development activities, though it is evident in their process that commercialization is an integral part. Figure 5 presents an overview of the entrepreneurship process theories.

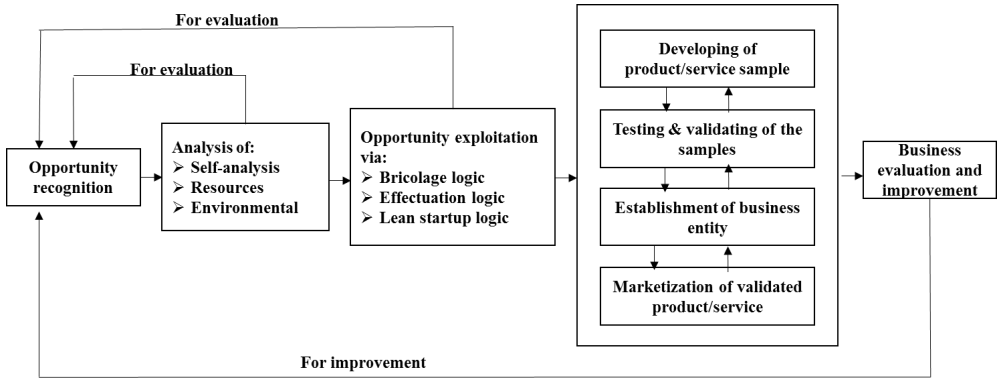
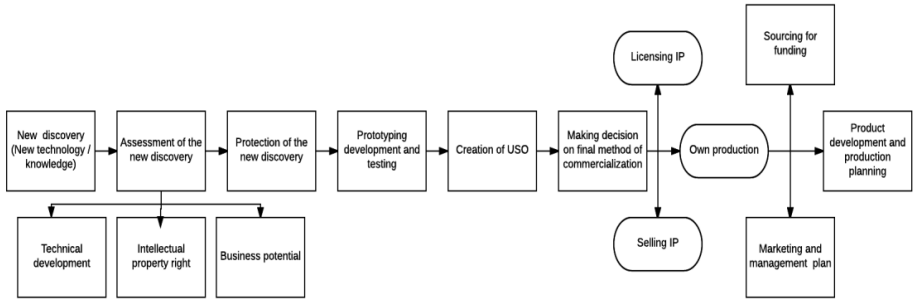


Figure 5: An Overview of Entrepreneurship Process Theories

2.1.4 The Spinoff Process and Transfer of Technology Models

In the introduction chapter of this study, it was stated that Spinoff and NPD are closely related, and they are branches of the innovation process theory. Therefore, considering Spinoff's theoretical frameworks and models in this study is crucial. Despite the fact that the Spinoff process attracted scholarly discussions, they focused on specific actors in the process. Those key actors in the process are new innovation, entrepreneur, parent organization and government. When their discussion centered on the innovation, the scholars explained its process (see: Lee & Gaertner 1994; Mustar 1997; Yencken & Gillin 2002). Such process is very similar (in most cases) to the innovation and the NPD processes. When the scholars focused on the entrepreneurs, their explanations are often on the entrepreneurship process (see: Hindle & Yencken 2004; Gübeli & Doloreux 2005). Likewise, when the scholars discussed the parent organization, they present organizational policies, culture and facilitating factors for the Spinoff process (see: Ndonzuau et al. 2002; Vohora et al. 2004). Similarly, some of the above-mentioned scholars discussed the government policies and entrepreneurship programs when they concentrated on the process. This situation made some scholars, such as Rothaermel et al. (2007), O'Shea et al. (2014), Simmons and Hornsby (2014) and Seguí-Mas et al. (2016), converge their knowledge of the Spinoff process. They asserted that the process follows NPD theoretical frameworks, making reference to, Vohora et al. (2002), Clarysse et al. (2002), and Shane (2004). When the work of the referenced scholars and their models were synthesized, it is learned that they all employed the Stage-gate theoretical framework. Meanwhile, their Stage-gate models are different from the original work of Cooper (1990). The scholars employed stages but did not emphasize on the *gates*.

Recent works from Slavtchev and Göktepe-Hultén (2016), Seguí-Mas et al. (2016) and Shakeel et al. (2017) noted that the Spinoff process is complex and complicated. They stated that the stage-based model process might not be completely suitable for Spinoff. Thereafter, alternative models proposed by Bradley et al. (2013) and Al Natsheh et al. (2014) were examined. Figure 5 shows an overview of the Spinoff models after the analysis.

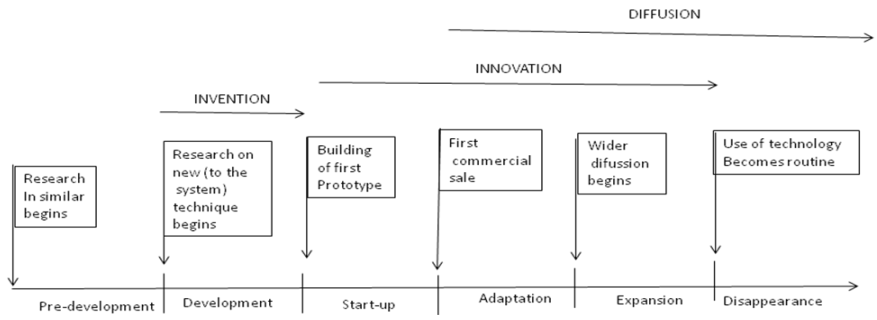


(Adapted from Gbadegeshin 2017b; 6)

Figure 5: An Overview of Spinoff Models

In view of the preceding synthesis, it can be noted that the Spinoff models seem to employ linear logic. It can be also noted that these models need be improved by considering all actors as well as considering the mixing of non-linear logic with linear logic. These improvements would make a new Spinoff model more flexible and adaptive for modern high technologies.

Furthermore, TOT is also important because it is highly related to NPD and entrepreneurship. Similarly, during the analysis of the Spinoff models, it was learned that TOT was well discussed (see: Bradley et al. 2013 and Al Natsheh et al. 2014 as examples) in relation to new technology-based companies and university Spinoffs. It was also learned that the TOT model considers the pre-innovation activities, innovation process and post-innovation activities. This model is quite similar to NPD models; the only difference is its *start-up* phase, which represents Spinoff. Figure 6 shows the TOT model.



(Adapted from Douthwaite et al. 2002; 114)

Figure 6: TOT Model

Therefore, it can be deduced that both the Spinoff and TOT models employ more linear logic than non-linear. The possible reason for this might be application of the Stage-gate model. Meanwhile, new high technologies, which are dynamic and need a quick commercialization process, demand non-linear logic, as the articles for this study shown (e.g., articles 2 and 4).

2.1.5 Marketing Field

The scholars from the innovation and NPD fields, such as Kotsemir and Meissner (2013), Cooper (2014, 2016), Barbieri and Alvares (2016), have noted that their processes have two cycles – technology and marketing. They explained that the technology cycle contains all activities relating to development and manufacturing of technology. They also explained that the marketing cycle is basically associated with the commercialization part of the entire process. Similarly, prominent marketing scholars have echoed the assertion as Mohr, and Sarin (2007) quoted Drucker (1954; 40): *any business enterprise has two—and only two—basic functions: marketing and innovation*. Mohr and Sarin (2007) pinpointed that the quotation is very relevant to technology-based companies. All these notes confirm marketing as an integral part of the innovation, NPD, Spinoff, TOT and entrepreneurship processes, especially for the high technology commercialization. Therefore, marketing is important field for the commercialization process. However, the marketing scholars, Mohr (2000), Mohr and Shooshtari (2003) and Bond III et al. (2008), have made it clear that the marketing of high technology is unique and requires different approaches from common technologies.

Marketing, as an established field, has several theories. Its theories are developed from other fields such as psychology, sociology and other social sciences.

There are also several theoretical frameworks for different parts of marketing, such as strategy, management and communication. Meanwhile, with respect to the current study's focus, marketing discussions on high technologies are examined through literature review. It is observed that from the works of marketing scholars (e.g., Barlow Hills & Sarin 2003; Mohr et al. 2005) that they focused very much on the characteristics of high technology. The main argument of these scholars for their focus is to enlighten companies and marketing professionals about the marketing activities for high technologies as well as to develop different techniques and strategies for them. In doing so, they employed some theories that include contingency theory (e.g., Gardner et al. 2000), market driving philosophy (e.g., Barlow Hills & Sarin 2003), and theory of diffusion and adoption (e.g., Heath et al. 2003; Yadav et al. 2006; Tellis 2008). These scholars affirmed the features of high technologies are uncertainty, high level of needed-inputs and unique outputs are the main distinct characteristics of high technologies. These scholars added that technology, market and competitive uncertainties are important features to be focused on when marketing high technologies.

In addition to those characteristics, the above-mentioned marketing scholars debated on how strategies could be developed for products, unlike other scholars from the aforementioned fields who mostly debated about companies and industries. The aforementioned marketing scholars outlined strategies for analyzing products, brand attributes of the products, communication and distribution, and purchase inducements for the high technologies. Their strategy discussions relate to debates in other fields on how to manage the product complexity of high technologies. Furthermore on the characteristics, the marketing scholars examined the roles of networks, specifically external networks, on the marketing of high technologies. The work of Cooper (2000), Sharma et al. (2008), and Borg (2009), have shown that use of internal and, most importantly, external networks facilitate the marketing of high technologies. They emphasized that the efforts of suppliers, governments, research institutes, and potential customers can mitigate the risk of market failure of high technologies. These scholars also argued that the role of networks is to support the collaboration and competencies of technology and market teams.

Besides the features of high technologies, the marketing scholars, such as Yadav et al. (2006) and Son and Han (2011), had investigated how high technologies could be diffused and adopted. These scholars found that innovativeness, ease of use and the perceived benefits of new high technologies made their users want to try and adopt them. Their finding is complemented by the empirical studies of Lee at al. (2011) and Vowles et al. (2011) which noted that the uniqueness, importance and added value of new high technologies determine their acceptability to the users. These empirical studies also noted that users might resist if they could not see clear differences between the new high technologies and existing

technologies. Despite the efforts of marketing scholars, it is pertinent to have knowledge about how digitalization tools change the marketing of high technologies, especially from the selected industries.

2.2 The Commercialization Process Models

It is learned from the literature review of commercialization that its process depends on the technology, the firm and the industry. It was also mentioned earlier that this study is contextualized to the ICT, Cleantech, and Life Sciences industries. Thus, the following paragraphs outline the common commercialization frameworks of the industries.

The ***ICT*** industry seems to be up-to-date in its commercialization model. According to Novickis et al. (2016), international standard bodies, such as Software Engineers, Capability Maturity Model, International Organization for Standardization, and International Electrotechnical Commission, state that the commercialization process for ICT comprises the technology transfer concept, initial market assessment, evaluation of transfer opportunities, technical analysis, intellectual property protection, market and competitive analysis, technology value evaluation, go-to-market estimation, commercial/social-economic interest confirmation, business case establishment, go-to-market strategy establishment, business plan establishment, and financing sources raising. These processes can be summed into these stages: develop first prototype, assess the prototype, improve the prototype, develop the final prototype and present the final solution (Novickis et al. 2016). The stages depict activities from point of innovation to point of marketing and sales.

Balachandra et al. (2010), Gaubinger et al. (2012), and Lavoie et al. (2017) are examples of studies that examined the commercialization process in the ***Cleantech*** industry. These studies affirmed that the commercialization process in the industry has different stages or phases. The stages are called different names, such as idea conceptualization or new technology discovery. The studies also outlined different activities for each stage. Despite the fact that the stages and activities are named differently, their descriptions revealed that the process starts from the discovery or recognition of a business application for a newly developed technology. The business application can be in a different form, such as a physical product, service, and solution (which sometimes combines products and services). Furthermore, the process moves to technology and prototype development and prototype testing. The process ends with marketization of the products. These studies' scholars noted that the process might be varied and highly dependent on the nature of the technology, commercialization team, and target market.

For the ***Life Sciences***, unlike the Cleantech industry, there are many studies on each sector of this industry due to its different sectors. Meanwhile, there are similarities in the models for each sector. For example, the commercialization model of NDD consists of discovery, pre-clinical, clinical trials, and marketing stages according to Khilji et al. (2006), the European Commission (2009), Sternitzke (2010), and Dogra et al. (2013). Likewise, the medical device commercialization model includes discovery, prototyping, testing and marketing stages in relation to the work of Maine and Garnsey (2007), Pietzsch et al. (2009), Abd Rahim et al. (2015), and Holzleitner (2015). Although e-health is associated with ICT, its commercialization model is different from other ICT models, because certain health-related regulations must be fulfilled. Hence, there are not many scholarly works on its model. Nonetheless, Cho et al. (2008) filled the gap by proposing a model that has the adoption, implementation, commercialization, and diffusion stages. Considering these sectors, it can be deduced that the frameworks have discovery, clinical trials or testing of prototypes, and marketing (which includes mass production and distribution).

The commercialization models from the above industries show that different new technologies pass through various stages before they reach their final customers. The stage starts with the discovery of a new invention or innovation (in this study, new high technology). The new technology is assessed in the second stage and developed further in the third stage, which is about prototyping, further development, testing and validation of the new technology. The last stage is final product development, production and marketization. These processes are discussed in the work of Datta et al (2013), Al Natsheh (2013a; 2014) and Gbadegeshin (2017b; 2019b). Thus, Table 3 summarizes and presents these processes.

Table 3: An Overview of The Commercialization Process Frames

Industries	**Cleantech**		**Life Sciences**			**ICT**		
Sectors	Measurement devices	Renewable/ sustainable energies	NDD	Medical device	E-health	Electronics	Optics devices	ICT solutions
Stage 1	New technology / Invention	New concept	Discovery:	New technology discovery	Adoption	New technology	New technology / Invention	New technology
Stage 2	Identification of technology application	Basic research	Recognition & evaluation of business opportunity	Evaluation	Implantation	Assessment	Identification of technology application	Applying new technology into a case study
Stage 3	Team building	Technical feasibility	Exploitation of business potential	Protection of IP	Commercialization	Protection	Team building	Evaluation
Stage 4	Developing business model	Development and designing	Testing	Prototyping	Diffusion	Prototyping	Developing business model	Technology engineering
Stage 5	Building supply chain	Engineering and manufacturing	Product development	Testing & further development		Production	Building supply chain	Technology embedment
Stage 6	Market entry	Marketing	Production & marketing	Product development & marketing		Marketing	Market entry	Marketing
Scholars	Al Natsheh et al.(2013a; 2014), Gbadegeshin (2017b)	Balachandra et al. (2010), Gaubinger et al. (2012), and Lavoie et al. (2017)	Khilji et al. (2006), European Commission (2009), Sternitzke (2010), Dogra et al. (2013), Gbadegeshin (2019b)	Maine and Garnsey (2007), Pietzsch et al. (2009), Volpatti and Yetisen (2014) Abd Rahim et al. (2015), Holzleitner (2015), Gbadegeshin (2019b)	Cho et al (2008), Gbadegeshin (2019b)	Novickis et al. (2016). Gbadegeshin (2018a)	Rogers et al. (2004) Al Natsheh et al. (2013a; 2014), Volpatti and Yetisen (2014) Gbadegeshin (2018a)	Punter et al. (2009), Novickis et al. (2016). Gbadegeshin (2018a)

Table 3 shows that the models employed the Stage-gate theoretical frame. Applying the stage model appears common in technology commercialization, which is developed by universities, research institutes and sometimes large corporations (Bradley et al. 2013; Still 2017; Gbadegeshin 2017b).

2.3 Summary of the Theoretical Frameworks and Commercialization Models

The innovation theories proffer the theory of diffusion, which also led to the theory of adoption for commercialization. In turn, the adoption-diffusion theory has two theoretical models: TAM and UTAUT. Similarly, the entrepreneurship theories outline Effectuation, Bricolage and Lean Start-up theories for commercialization. Likewise, the TOT theory just offers a theoretical framework that is very similar to NPD. It is also noted that marketing scholars make use of TAM and UTAUT. Hence, it can be deduced that the selected fields of this study employ TAM, UTAUT, Stage-gate, Effectuation, Bricolage and Lean start-up theoretical frameworks. Figure 7 shows the employed frameworks of the study.

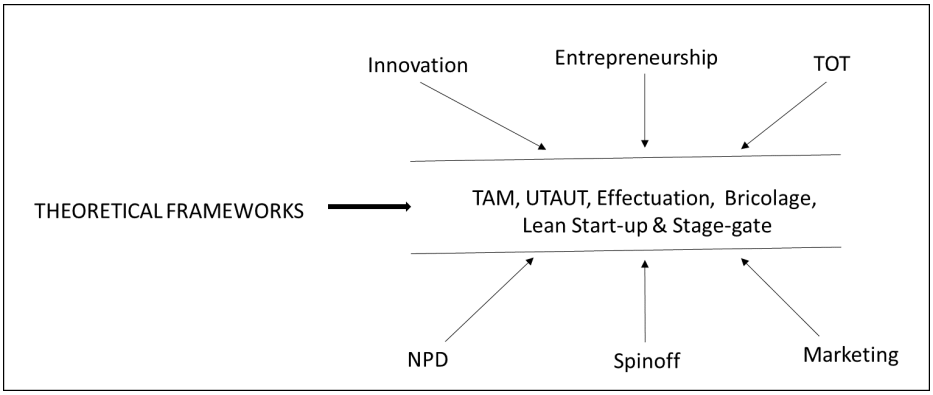


Figure 7: Theoretical Frameworks of the Study

Besides their contributions, each field has some weaknesses in relation to the commercialization process. First, the Adoption-diffusion theory asserts that information about innovation needs to be diffused and users would accept and adopt the innovation. This assertion is weak and is criticized by scholars such as Hyvönen and Repo (2005), Straub (2009) and Hoffmann (2011). Their criticism includes the incomprehensibility of theory's frameworks, the descriptive nature of the theoretical frameworks and the failure to depict how adoption happens. Supporting the above criticisms, the empirical findings of this study showed that the adoption-diffusion theory not seems suitable for the commercialization of high technologies. The theory is weak when providing answers to the following questions:

(a) When information on an innovation needs to be diffused; specifically, at which stage of innovation process?

(b) Now that digitalization makes much information available online and consumer knowledge has improved, what type of information should be diffused to avoid making details of an innovation available to competitors? This question is also raised by Atkin et al. (2015).
(c) When should adoption should start to be applied? This is disputed by Straub (2009; 641), who said that:

> *The adoption and diffusion process can be viewed as having the broad characteristics of a developmental theory—change is relatively slow and relatively orderly. Most adoption theories discuss technology adoption in terms of stages, and although most of the stages are not clear cut, they do suggest a progression of knowledge and understanding."*

Additionally, this study's findings, especially from the article 2 and 4, showed that there are many factors associated with acceptance of high technologies. The assumptions that value, compatibility, complexity, trialability and observability would determine adoption of Adoption-diffusion theory appear to be insufficient for the high technologies. For instance, new regulations influenced the commercialization process of case study technologies in the articles 2 and 4. If any new policy would compel companies to use a new technology, the previously mentioned factors of the theory would not be the main determinants for adoption.

Second, TAM and UTAUT are widely tested. However, it is learned from the previous studies (see: De Sena Abrahao et al. 2016; Olaleye et al. 2018) that the scholars examined the models with ICT-related innovations or technologies. Therefore, it cannot be affirmed that the models are applicable to other high technologies from regulated and complicated industries, such as Cleantech and Life Sciences. It is also learned from the models' tests and theoretical assumptions that the models were tested with quantitative studies. Meanwhile, qualitative studies are essential to gain better understanding of commercialization process. as explained earlier in this study.

Third, the Stage-gate model has weaknesses, despite its wide acceptance for NPD, Spinoff and TOT. Some scholars which include Bradley et al. (2013), Al Natsheh et al. (2014) and Gbadegeshin (2017b) argued that the model is rigid and does not consider differences in technologies and their environments. Its theorist, Cooper (1990) *ab initio* notified the users of his theoretical framework that: *although conceptually quite simple, as we shall see later, the intricacies, design, and operationalization of stage-gate approaches are considerably more complex* (Cooper, 1990; 44). These criticisms led the theorist to make his recent frameworks (see: Cooper 2014, 2016, 2017) flexible, customizable and agile. In spite of the new versions of the model, it is learned from the findings of the current study that the model does not consider changes of digitalization and entrepre-

neurship roles. Similarly, it is learned that the model focuses on the radical innovations and does not consider services or solutions as an end-result of the NPD process.

Fourth, it is noted that other models of Spinoff and TOT belong to first - third generations of innovation process theories. Similarly, it is observed that the models do not consider key different actors' roles at the same time. Likewise, the models showed that its scholars have not considered roles of digitalization on the process. These issues make the models weak in relation to the commercialization process.

Fifth, Entrepreneurship theories are also weak in answering this: *how does the process relate to the commercialization process*? This question needs to be answered if the commercialization process is to be well understood. It is agreed that Figure 4 (shown earlier) depicts that the entrepreneurial process is ambiguous and heterogeneous. One reason for its ambiguity is that the entrepreneurial effort entails a series of steps. The steps are not an event, as explained by Shane and Venkataraman (2000). Still, it is essential to know how these steps relate to commercialization activities or its process.

Sixth, the marketing scholars proposed different strategies and tactics, tested different theories on adoption and consumers behaviors, and even suggested that a course should be established for it (e.g., Mohr 2000). It is noted that the scholars have not yet investigated the role of digitalization on the marketing of high technologies. In other words, there is limited work on the impacts of digitalization on the marketing of high technologies. Although some works such as Salo (2006) and Chung (2011) investigated digitalization in marketing, they did not focus on the changes to digitalization in the commercialization process of high technologies. For instance, Salo (2006) examined how business relationships could be digitized by looking at companies of high technologies. Similarly, Chung (2011) examined the role of the buzz online with new product diffusion; there is still a need to understand the different forms of digitalization on the commercialization of high technologies (from a marketing perspective).

Furthermore, the commercialization process models have common logic though their activities and their stages may be varied. Some scholars such as Al Natsheh et al. (2014) and Gbadegeshin (2017b) argued that the stages may not be followed necessarily. Their argument was initiated by Cooper (2014; 2016), Brettel et al. (2016) and Parviainen et al. (2017), who argued that flexibility is essential in the commercialization process for modern advanced technologies. Similarly, Mettlera and Eurich (2012) and Volpatti and Yetisen (2014) add that parallel development of the product and market is an important step in the commercialization process. However, these researchers of commercialization models have not yet discussed how digitalization changes the process, and they have not

yet examined the process from multiple contexts. Thus, these two issues seem to be missing in the existing commercialization process models.

Now, considering all the previously discussed weaknesses of the theories, theoretical frameworks and models (from the commercialization standpoint), it can be argued that they are relevant for the commercialization process but that they need to be improved in order to be suitable for newly developing high technologies. Among the reasons for their improvement are uncertainty, short life cycle and digitalization of modern high technologies. Another reason is that the theories are mostly tested with ICTs, whereas the high technologies from traditional and highly regulated industries such as Life Sciences and Cleantech must be researched empirically. Additionally, Straub (2009) argued that complexity and the social and developmental nature of technology weaken the previously mentioned innovation theories and their theoretical frameworks. The scholar recommended that the new model for the commercialization part of innovation has to be cognitive and contextual. Furthermore, most of these synthesized theories, theoretical frameworks and models employed linear logics, whereas the high technologies are complex and complicated. Hence, employing both linear and nonlinear logics seems to be appropriate, as many scholars have argued (e.g., Conforto & Amaral 2016; Gbadegeshin 2017b) and as the articles of the current study have shown.

3 RESEARCH METHODOLOGY

Considering the goal and research questions of this study, the qualitative method was employed. This method is strongly recommended by the commercialization researchers, such as Pellikka (2014), Prebble et al. (2008) and Siegel et al. (2004). These scholars also specifically stated that the case study method would be more suitable for researching the process and argued that this method would facilitate a better understanding of the process, especially from the selected industries. Hence, the case study was employed. This method provides in-depth knowledge on a specific phenomenon according to Yin (2003). Denzin and Lincoln (2000) add that the method facilitates a better understanding of the phenomenon for the researchers. Eriksson and Kovalainen (2008) agree that the method is a suitable research tool for empirical studies because it uses qualitative research instruments that include interview and observation. Thus, this chapter presents the details of this study's methodology.

3.1 Research Method and Instruments of the Study

This study purposely employed the case study research method to gain in-depth knowledge about the commercialization process as it is suggested by Walsh (2012) and Lavoie et al. (2017). The method was employed to gain a better understanding of the commercialization process of high technologies in the studied contexts. Additionally, the method was purposely employed to investigate the process in real-life situations. This reason was enumerated by Järvinen (2004) and Ellis and Levy (2009), who stated that the case study method is highly useful when an issue needs to be investigated in a real-life situation.

Generally, the case study method is useful for empirical studies (Eriksson & Kovalainen 2008; Creswell 2009) and when a specific problem needs to be examined (Shank 2002; Yin 2003). It is very useful for exploring and describing a phenomenon (Yin 2003) and providing in-depth knowledge on an issue (Ellis & Levy, 2009). It is also suitable for studies whose research question starts with *How* (Yin, 2003) and their theme is based on experience or practice (Shank, 2002). The method enables critical interpretation and replication of studies (Yin 2003; Eriksson & Kovalainen 2008). Hence, the method was employed for this study because of these reasons.

Furthermore, there are many types of case studies, one of which is the multiple case study. According to Yin (2003) and Creswell (2009), the multiple case study enables researchers to have knowledge about differences and similarities of a phenomenon and facilitates comparisons so that in-depth knowledge can be derived. These explanations are in line with the suggestion of Pellikka (2014) and Lavoie et al. (2017), who recommended the multiple case study for studies on the commercialization process. These scholars even recommended that the case can be selected from different industries, technologies and stakeholders. Therefore, the multiple case study was employed to achieve the goal of the current study. Specifically, the high technologies of selected industries were the focus of the current study. Information about the technologies was collected from the companies of the selected industries. Hence, the stakeholders of the industries were the participants for this study. Notably, the stakeholders were represented by the Chief Executive Officer (CEO), Chief Technology Officer (CTO), Business Development managers and Innovation managers for the companies, as well as Business advisors, Innovation managers and Executive Directors for the incubation centers and government agencies.

Yin (2003) and Creswell (2009) advised that a multiple case selection should be carefully and systematically done in order to attain meaningful comparisons. Following this advice, criteria were developed for the industries, companies and their technologies, and stakeholders. For the industries, the criteria were that (1) it must have a high level of R&D activities, (2) it must have many sectors, (3) its production must be capital- or resource-intensive, (4) its products and services must be applicable to or useful for other industries, and (5) its market must be global. Based on these criteria, 3 industries were selected, and they represent the empirical context of this study. For the companies, these criteria were developed: (1) it must operate in one of the selected industries, (2) its products and services must make use of high technologies, (3) at least one of its owners must be an innovator, and (4) it must operate in the international market. With these criteria, 40 companies were selected and participated. For the high technologies, their features, which include high level of R&D, risk, complexity, uncertainties, advanced development, and possibility of industrial applications, were used as criteria. For the stakeholders, experience with the commercialization process was the main criterion. Other criteria are presented in Table 6.

According to Yin (2003) and Eriksson and Kovalainen (2008), the case study might be longitudinal, or researched over a period of time, for instance, years. This kind of case study was also recommended by the commercialization process scholars, which include Zhao (2004) and Datta et al. (2013), who stated that a longitudinal case study would provide deep insight into the process. Mustar et al. (2006), Djokovic and Souitaris (2008) and Evers et al. (2016) also mentioned that a longitudinal case study of Spinoff companies would provide a better un-

derstanding of the commercialization process. For their reasons, the current study used a longitudinal approach in articles 2 and 3. The longitudinal data were collected through observation, documents and secondary sources. All these data collection instruments were used in article 2. Specifically, participatory observation was used in the article 2, and all documents associated with the case study technology were used. The observation data were collected for 3 years, and notes on the data were made monthly. Secondary data, which include newspaper and website information, were also used for article 2. The secondary data were collected in the last year of data collection. For article 3, non-participatory observation and secondary data were collected. Both observation and secondary data were collected by monitoring the companies' websites, business information organizations, and news. The data were collected on a monthly basis for three years and were recorded accordingly.

About the research instruments, this study used these instruments: interviews, observations, documents, and surveys. These instruments are commonly used for the case study method (Yin 2003; Hox & Boeije 2005). The interview was used for this study basically to enable its researcher to clarify the study participants' responses. It was also used to enable dialogue between the researchers and the study's participants. Similarly, the interview was used to observe and deduce the study participants' nonverbal actions and reactions. These reasons are echoed by scholars, such as Yin (2003) and Creswell (2009), who stated that interviews produce qualitative data that can be logically analyzed and interpreted. Silverman (2011) argued that a dialogical interview leads to deep insights for a study. Thus, the interviews conducted for this study were dialogical. This instrument was used in all articles of this study. Although there are structured, semi-structured and unstructured types of interviews, this study used the semi-structured interview in its articles. The semi-structured interview was used to achieve the aforementioned benefits of this research instrument.

The observation instrument was also used, mainly to enable this study's researcher to verify the collected data and to monitor the commercialization process remotely. It was also used so as not to disturb the interviewed study participants due to their tight schedules. The instrument was also used as one of the primary research instruments for longitudinal studies. Last, this instrument was used to reduce the study participants' subjective biases and to validate their interpretations of the collected information. These reasons are aligned with the claims of Kothari (2008), who argued that the observation instrument eliminates subjective bias, reveals the current situation and the reality of phenomena and supports a better understanding of a study's topic. That scholar noted that these advantages of the observation instrument are often attained when the process is semi-structured and well recorded. These conditions were fulfilled in this study. The collected data from this instrument were verified by comparing the transcrip-

tion of the interviews with observation notes and documents. For instance, observation records were compared with official documents and public information about the case technology and its company in article 2. Similarly, observation notes were compared with the initial and final interviews of the study participants for article 3.

Documentary was used only in article 2. This instrument was used purposely to acquire first-hand, robust information. According to Bowen (2009), O'Leary (2014) and Silverman (2011), this research instrument is useful when there is a need to acquire direct and formal information about a phenomenon. These scholars argued that the instrument seems to provide better verified information than the interviews and questionnaires. The scholars asserted that this instrument enables researchers to gain insights. Mustar et al. (2006), Djokovic and Souitaris (2008) and Evers et al. (2016) additionally stated that using the first-hand information would provide in-depth knowledge on a longitudinal study of the commercialization process (though they focused on university Spinoffs). In view of these reasons, the documentation research instrument was used for this study's data collection. Both private and public documents were used.

A survey instrument was used purposely to validate the qualitative data collected for the article 1. This instrument is a quantitative method and can be used for qualitative studies, especially when initial results of such a study must be verified. It was used because the initial results of article 1 needed concise information. This reason was claimed by Taylor-Powell (2001), who argued that a survey instrument facilitates data interpretation and provides precise information about a phenomenon. The article 1's survey contained both numerical and descriptive data.

In the case study method, the level of analysis is important according to Yin (2003) and Järvinen (2004). Thus, the level of analysis in the cases of the current study is high technology. The companies and other stakeholders were regarded as informants for the technologies' commercialization process.

Above all, the aforementioned research instruments were used together to ensure that the right information was collected from the right sources so that the right knowledge could be derived. Similarly, these instruments were used to triangulate this study's collected and analyzed data. Triangulation promotes a study's validity and reliability. According to Yin (2003), Eriksson and Kovalainen (2008) and Creswell (2009), it also enables researchers to gain wide knowledge about their study, while they deduce meanings from their investigation. The following Table 4 provides details about the instruments and study participants.

Table 4: The Research Instruments and the Study Participants

Article	Research instruments	Study participants			
		Industry	***Expertise / Position***	***Type of Stakeholder***	***No***
1	Interview	ICT-Cybersecuirty	Technology entrepreneurs / CEOs	Innovator	4
	Survey		Professors, Researchers & Managers of QKD technology	Innovators, TOT offices & Incubation centers	60
2	Interview	Cleantech	Innovators, Innovation managers, Researchers, Business advisors, CEO & Government agent	Innovator, TOT offices & Incubation centers	17
	Participatory Observation		The study company and all stakeholders		
	Documentary		All private and public documents		96 docs
3	Interview	Cleantech, ICT and the Life Sciences	CEOs & Business advisors	Innovator, TOT offices & Incubation centers	6
	Non-participatory Observation		The companies and their technologies		20
4	Interviews	The Life Sciences	CEO/CTO, Business developers, Business advisors, Director & Innovation managers	Innovator, TOT offices & Incubation centers	16

The current study collected most of its data from Finland, although some study participants come from other European countries. Why Finland? Because it is one of the leading countries in innovation and is always among the top ten countries in the global innovation index. R&D investment and activities, the level of productivity and the rate of high technology exports are among the ranking criteria for countries (World Intellectual Property Organization – WIPO 2017). Similarly, Finland maintains its leading position in the global competitiveness index, in which technological readiness and innovations are among the criteria for the ranking (World Economic Forum 2017). These facts make Finland a suitable geographical context for the current study. Additionally, Finland has international recognition in the above-mentioned industries. For example, Finland is one of the top three leading countries in the world according to Sworder et al. (2018) when explaining The Global Cleantech Innovation Index 2017. This is supported by statistics from Finland's Ministry of Economic Affairs and Employment (2018), which states:

> *Cleantech helps us respond to global environmental challenges, such as environmental pollution, climate change and resource scarcity. At the same time, they improve the competitiveness of the industry and services thanks to the efficient use of materials, energy*

and other resources. Generating a combined annual turnover in excess of €25 billion, the Finnish cleantech sector comprises around 2,000 enterprises, some 100 of which are large companies.

3.2 Research Process of the Study

The case study method is relevant for this, but it is crucial to use the method systematically (Yin 2003). A systematic procedure ensures and promotes the method's credibility (Shank 2002; Yin 2003; Creswell 2009). Thus, the following steps were followed for the articles in this study. First, reading the literature was performed for each article. Reviewing previous studies is purposely recommended by Ellis and Levy (2009) and Gray (2013) for understanding the phenomenon to be studied and its related theories, as well as for familiarization with similar approaches and the underpinning terms. Hence, both old and recent existing literature relating to each article's topic for this study was examined. For article 1, the literature on commercialization challenges was reviewed. For articles 2, 3 and 4, the literature on commercialization frameworks was synthesized. In addition, for the article 2, the literature on the university Spinoffs was examined, and recent scholarly work on the Lean start-up method was reviewed for article 3. Likewise, for the article 4, the literature on digitalization and Life sciences was considered. Furthermore, the literature on innovation, NPD, Spinoff, TOT, entrepreneurship and marketing was studied. Similarly, the literature associated with key terms such as commercialization and high technology was reviewed. The literature review was conducted through these processes: (1) search for keywords, (2) collect relevant articles after reading their abstracts, (3) read, annotate and analyze relevant articles, and (4) summarize the main themes of articles. These are in line with the recommendations of Steward (2004) and Torraco (2005), who stated that conducting the literature review through the above process would provide a thematic focus on the research phenomenon. The scholars also stated that such literature review enables researchers to identify key themes, debates and discussion of a specific topic. Torraco (2005) added that this kind of literature review can be described as an integrative literature review that combines related works and provides a core knowledge or message of the previous works.

Second, subresearch questions for the articles were developed. These questions were derived from the objective and RQs of this study. Articles 1 and 4 had a specific subreseach question, while article 2 had three subresearch questions. Article 1's subresearch question was: *What are the challenges that can hinder the successful commercialization of QKD technology?* This question aimed to provide answers to RQ1 and RQ2. Article 2's subresearch questions were: (i)

How does a university Spinoff commercialize its high technology?, (ii) *Does the university Spinoff follow the stage-gate commercialization process*? and (iii) *Why does the university Spinoff succeed in its commercialization adventure*? These questions provided information for RQ1 and RQ2. Article 3 did not have an explicit subresearch question, but it did imply a question that related to RQ2. Article 4 asked this subresearch question: *How does digitalization influence the commercialization process of high technology companies in the Life Sciences industry*? That question provided insight for RQ2 and RQ3.

Third, selection criteria were developed for the study's participants. Based on the criteria, targeted study participants were identified. Then, the entry modes to be used were outlined. In this study, telephone call, introductory emails, and use of interpersonal contacts were used to reach the study participants. Table 5 shows the types of study participants and the entry mode. More details on the participants are provided in the next subsection (3.3).

Table 5: Selection of the Study's Research Participants

Article	**Study participant criteria**	**Entry mode**
1	Interviewees: an innovator in QKD field	Introductory email, interpersonal contact
	Survey: a stakeholder in QKD technology	Introductory email
2	Interviewees: a stakeholder in Cleantech	Interpersonal contact
3	Interviewees: a stakeholder in ICT, Cleantech and Life Sciences	Telephone call, introductory email, and interpersonal contact
4	Interviewees: a stakeholder in the Life Sciences industry	Introductory email, interpersonal contact

Fourth, interview questions were developed. The interview questions were developed from the RQs and the subresearch questions. Thus, different interview questions were developed for each of the study's articles, but all the interviews contained background information and ethical questions. Yin (2003), Järvinen (2004), and Gray (2013) emphasized that ethical issues such as the participants' consent confirmation and confidentiality must be noted in the interview question. Similarly, these scholars explained that the key terms of study phenomenon must be clarified for interviewees in relation to their experience. These issues were addressed at this stage of the research process. For instance, the study participants were first asked about the confidentiality issues and anonymity before any interview started. Likewise, the key terms which include c*ommercialization*, *innovation process*, *high technology* and *digitalization* were defined and clarified at the beginning of each interview.

Fifth, the participants were contacted and recruited. This activity was mostly performed in parallel with the development of the selection criteria for the study participants and the interview questions. Once any study participant group was

identified, a list of the potential participants was outlined, and they were contacted with an introduction to the main research question and goals of the study. At this stage, those who responded positively were requested to make a schedule for the interview or received a survey link. This activity for was performed for all the articles.

Sixth, the interviews, survey and observations were conducted. Guidelines provided by scholars such as Shank (2002) and Gray (2013), were followed for conducting the interviews, survey and observations. For the interviews, the ethical issues were handled first, then the background information to determine relevance of the study participants. When these issues succeeded, the subresearch questions followed. For all the articles, the study participants agreed to be recorded and their background information, company, organization, product or solution agreed to be used anonymously. Similarly, the subresearch questions were open ended so that the study participants could express themselves freely. Additionally, the whole interview process was dialogical to cocreate an understanding of the issues discussed, as Silverman (2011) recommended. At the end of the interviews, the participants were asked for their availability for discussion. In some cases, permission to follow their products and updates was requested from them, to which they agreed. The interviews conducted were face-to-face, telephone, and Skype. The face-to-face interview was used in all articles; telephone and Skype interviews were used for article 2. The survey was used only in article 1; it contained background, subresearch and validating questions. Its questions were multiple choice, but there were spaces for the participants to state their reasons for their selected choices.

Seventh, data collation was performed. All interviews were recorded with digital voice recorders and transferred to a personal computer. Likewise, survey data were first saved on the software website and later transferred to the personal computer. The observation data were saved on the personal computer. As part of the observations, documents used in article 2 were retrieved from the organization's database after receiving permission from an authority. Similarly, links for public information used in the observations were saved on the personal computer. All information was saved anonymously on the personal computer. Also, at this collation stage, interviews were listened to several times and notes were made on them, while the survey results and documents were read often and noted were made.

Last, the data were analyzed, and the results were presented. This was the last step of the research process for each article. The qualitative data, survey, and observation methods were analyzed with content and thematic methods, while the quantitative data were analyzed with descriptive statistics. With the content and thematic analysis techniques, qualitative data were systematically reduced by focusing on key points and summarizing the points. The points were later inter-

preted to provide meaning. These processes were guided by the work of Miles and Huberman (1994), Braun and Clarke (2006), and Silverman (2011). These techniques were used for all articles. However, descriptive statistics were used only for article 1. This technique shows basic and important information from the data. It presents frequencies and percentages of data. Its process was guided by the work of Taylor-Powell (2001). The data analysis techniques were used in accordance with this study's research method and goals. These techniques have been described as tools that are appropriate for a case study approach, according to Yin (2003) and Easton (2010). The current study's findings were presented in understandable formats. Most of the results were summarized into simple sentences and were explained as they were interpreted by the current study's researcher. The quantitative results were presented in table form and were also explained to denote their interpretations. Figures and diagrams were used to pinpoint the findings. Most importantly, the findings were explained in relation to the previous studies.

Table 6: Summary of the Research Process

Steps	**Article 1**	**Article 2**	**Article 3**	**Article 4**
1: Literature review	Commercialization, commercialization process and commercialization challenges	Commercialization, commercialization process, commercialization challenges and university Spinoffs.	Commercialization, commercialization process, commercialization challenges and Lean startup methodology	Commercialization, commercialization process, digitalization, high technology, and life sciences
2: RQs	What are the challenges that can hinder successful commercialization of QKD technology?	(i) How does a university Spinoff commercialize its high technology? (ii) Does the university Spinoff follow the stage-gate commercialization process? and (iii) Why does the university Spinoff succeed in its commercialization adventure?	How can high technologies be commercialized *(not-explicitly stated)*	How does digitalization influence the commercialization process of high technology companies in the Life Sciences industry?
3: Selection criteria for study participants	(i) interview; experience, nature of the commercialized (or commercializing) technology, availability of participant group and interviewee is an innovator in QKD (ii)Survey: participants should be a stakeholder of QKD technology	Experience, nature of the commercialized (or commercializing) technology, participant group availability and participants should be a stakeholder of Cleantech	Experience, nature of the commercialized (or commercializing) technology, availability participant group and participants should be a stakeholder of Cleantech, ICT and Life Sciences	Experience, nature of the commercialized (or commercializing) technology, availability participant group and participants should be a stakeholder of Life Sciences.
4: Interview and survey questions	(i)Interview questions: back-ground information, ethical questions, research questions and request for observation (ii)Survey questions: background information, ethical questions and research questions	Background information, ethical questions, research questions and request for observation	Background information, ethical questions and research questions.	Background information, ethical questions, research questions and request for observation
5: Study participants	(i)Interview: 6 participants (ii) Survey: 60 respondents.	17 participants.	(i) 2 participants in 2012. (ii) 4 participants in 2017.	16 participants
6: Type of Interviews, Survey and Observations	(i)Interview: face-to-face (ii)Survey: Online	(i)Interview: face-to-face, telephone, and Skype. (ii)Observation: participatory	(i)Interview: face-to-face. (ii)Observation: non-participatory	Only face-to-face interview
7: Collation of data	(i)Interview: recorded, transcribed and saved anonymously. (ii)Survey: retrieved from service provided and saved.	(i)Interview: recorded, transcribed and saved anonymously. (ii)Observation: retrieved documents and saved anonymously.	(i)Interview: recorded, transcribed and saved anonymously. (ii)Observation: documented and saved anonymously.	(i)Interview: recorded, transcribed and saved anonymously.
8: Analysis of data and presentation of results	(i)Qualitative data: content analysis method (ii) Quantitative data: descriptive statistics	(i)Document analysis (ii)Content analysis	Content analysis	Thematic analysis

3.3 The Study Participants

The study's participants are stakeholders in the commercialization process. They engage in several activities of the commercialization process. There might be many stakeholders for commercialization of high technologies depending on the nature of the technology, the type of commercializing team or company and the industry. Meanwhile, some scholars which consist of Peters et al. (2004), Abd Rahim et al. (2015) and Kirchberger and Pohl (2016) have noted that the inventor / innovator, university technology office (UTTO), incubation center, and business development play important roles in the commercialization of technologies. These scholars also note that these stakeholders could facilitate the process, and their decisions can also hinder the process, as shown in article 2. Therefore, these stakeholders were considered for this study. They are common stakeholders for commercialization of high technologies or high technology-based companies. Hence, they are explained here.

(a) Inventor / Innovator: literarily, an inventor is a person or a group of persons who discover a new technology/knowledge/technique. Likewise, an innovator is a person who develops a new improvement on an existing technology/knowledge/technique. Meanwhile, and in the entrepreneurship context, both of them refer to someone who transforms the new technology or improvement of existing technology into products and services by establishing a company. The inventor and innovator are mostly referred to as academic entrepreneurs (Franklin et al. 2001; Meyer 2003). Inventors and innovators were interviewed for all articles in this study.

(b) University Technology Transfer Office: this unit of a university is responsible for a new technology evaluation, IP analysis, licensing, and entrepreneurship training. It is a connection between the university and industry. The main goal of the unit is to commercialize any invention or innovation developed by the university (including research institutes). Thus, this office is an integral stakeholder of any commercialization process (Phan et al. 2005; Debackere & Veugelers 2005). Articles 2 and 4 of the study interviewed senior staff of the unit.

(c) Incubation Centre: this is an institution that helps start-ups and small enterprises to grow. It usually provides complementary resources such as offices, laboratories, advisory services, networks, and trainings. It is mostly owned by government and is widely managed by government entrepreneurship policies, although some private persons can own and manage it (Cooper 1985; Peters et al. 2004). Furthermore, a part of this institution that is responsible for launching and promoting new business is known as Business Development. This section is often headed by business experts or experienced entrepreneurs. Business advisors and business development managers were also interviewed in articles 3 and 4 of this study.

3.4 Validity and Reliability of the Study

Assessing the research methodology is essential in social science studies (Powell 2006) to create and maintain their trustworthiness (Eriksson & Kovalainen 2008). The assessment also determines the robustness of studies that use qualitative methods (Horsburgh 2003; Long & Geoffrey 2004). Meanwhile, using quantitative tools to evaluate qualitative research may make the qualitative studies into non-standard academic work. Thus, it is essential to use qualitative tools to determine a study's robustness (Horsburgh, 2003; Long & Geoffrey 2004). Validity and reliability are among the tools used to determine the credibility of qualitative studies (Morse et al.2002; Yin 2003; Eriksson & Kovalainen 2008). Despite the importance of validity and reliability, they are difficult to do in qualitative studies due to the large volumes of data (Golafshani, 2003). Several methods exist to validate and test reliability of qualitative data to ease this inherited problem (Last 2001). Each method depends on a study's research methodology (Merriam 1995). The following validity and reliability strategies were used for this study.

Strategies to improve validity: Merriam (1995) and Last (2001) stated that validity strategies include triangulation, researchers' statements and engagement, all of which were employed in this study. These scholars described triangulation as the use of more than one research method, research instruments, data and theory. The scholars added that triangulation ensures that the disadvantages of using a specific method (e.g., research) are minimized when such a method is combined with other means. For example, it is established that the quantitative research method has a problem in providing in-depth insight into a phenomenon (see: Creswell 2009). This problem might be reduced through triangulation with qualitative method.

In this study, research method, data and theory triangulations were used. The triangulation research method used was a combination of qualitative and quantitative methods and a combination of two research instruments, which were complementary to each other. Use of the qualitative method provided insight, while using the quantitative method buttressed the insight. Their complementarity was shown in article 1. The combination of interview and observation research instruments in the current study was also complementary and confirmatory. The interview provided raw information, which was later confirmed from the observations. Similarly, a documentary instrument provided some pieces of information, which were later validated with the interviews and observations. The triangulated research instrument was used in articles 2 and 3.

For the data triangulation, a combination of primary data (interviews) and secondary data (observation and public information) was used. The primary data provided basic knowledge, and the secondary data supported that knowledge.

This triangulation revealed that the basic information derived from the primary data appeared to be truthful because the secondary data referred to it, even over a period of time. Additionally, different sources (informants) of data were used as data triangulation of the current study. The data collected from the CEOs/CTOs, business developers and managers and innovation managers served as primary data that provided basic information. Their information was complemented by the information from the business advisors, university technology transfer officers and government agents. This triangulation also revealed that the first set of informants had direct, specific and first-hand information, while the second set of informants had multiple and general information. This lesson was noted in the selected industries. The data triangulation data were used in all articles.

For the triangulation of theories, different theoretical frameworks and models were used in each article. This triangulation is needed because of the nature of the commercialization process. In article 1, a marketing strategy was used, but in article 2, a Spinoff model and marketing strategy were used. A comparison of the two articles shows that combining the two theoretical frameworks provided more understanding of the commercialization process than the single model. This resulted in using the triangulation of frameworks and models in articles 3 and 4. Article 3 applied the Lean start-up but triangulated it with the Bricolage and Effectuation of entrepreneurship theories. Article 4 used different commercialization models.

Above all, the triangulation strategy was purposely used to broaden the view of the researcher of this study and to minimize the weaknesses of each method or information source. The second validity method used in this study was the researcher's statement. Merriam (1995) and Golafshani (2003) refer to this strategy as a presentation of the researchers' potential doubt or misunderstanding of the research work to the study's audiences. In all articles, the researcher in this study explained his opinion and his relationship with study participants. More specifically, in article 2, the researcher of the current study mentioned that he was part of the commercialization team for the case study technology and its company. This strategy was used to define the research process, its assumptions and biases.

The third validity strategy for this study is engagement. Merriam (1995) and Last (2001) describe this strategy as a means of carrying research actors through the process. The research actor includes study participants, other researchers, funding organizations and beneficiaries of the research. In this study, the study participants and other researchers were the main research actors. These actors were well-informed about the research process of the current study. This strategy was used in all articles. In articles 1 and 2, the study participants were given updates on their interviews for comments. Similarly, in articles 1 and 2, the other researchers were informed about the use of data collected. In articles 3 and 4, the study participants were informed about the research and how their data would be

used for the study. The engagement strategy was employed in this study because the researcher wanted to have sufficient knowledge or a better understanding of his study so that the goals of the study would be attained. All these validity strategies were recommended by Morse et al. (2002) and Eriksson and Kovalainen (2008) as important tools to assess qualitative studies like the current study.

Strategies to improve reliability: the main purpose of reliability is to ensure a study's repeatability. Hence, Merriam (1995) and Last (2001) list triangulation, peer examination and audit trails as common reliability strategies. This study employed all of them. The application of the triangulation strategy in this study was previously explained. Peer examination was used by asking fellow and senior colleagues to examine each article. Mostly, dissertation supervisors, colleagues in the same department and other departments, and friends from other institutions and practitioners were used for the articles. Most importantly, anonymous reviewers were used for the articles. The comments and feedback of the peer examiners helped the research to improve and show transparency in the research process. Furthermore, an audit trail is described as a strategy where detailed information on the research process is provided according to Merriam (1995) and Golafshani (2003). In the articles of this study, this study's researcher supplied all the necessary pieces of information about his research process via diagrams. This study's researcher drew and explained the entire research process for each article. Among the information provided by the researcher as part of his audit trail are the details of the study participants, the selection procedure for the participants, the data collection and analysis methods, the result summaries and the interpretations of the results. The reliability tools employed by this study were supported by the work of Morse et al. (2002), and Eriksson and Kovalainen (2008)

Apart from the preceding, Eriksson and Kovalainen (2008) suggested that validity and reliability can be established in qualitative studies by providing these features: dependability, transferability, credibility, and conformability. These scholars explained that dependability is a responsibility of the researchers to provide detailed information on the research process; transferability is the ability of the study to relate to similar or previous scholarly works. The scholars explained further that credibility is the ability of researchers to show their familiarity with the topic, a logical presentation between the collected data and their analysis, and a relationship between the analysis and the claims (findings). Conformability is linking the results with purpose of the study and making a logical presentation of the research. In relation to these scholars, this study's researcher ensured that he had knowledge about his topic, selected the relevant participants, conducted the study with sufficient time and analyzed the data with the right methods and tools. He also ensured that both interview and survey questions had some counter ques-

tions, and he tried to ensure that the collected data were validated. Similarly, all feedbacks, comments and criticisms of external reviewers, dissertation supervisors, and senior colleagues were considered during the research process of the articles and while analyzing them for this study.

4 SUMMARY OF ARTICLES FOR THE STUDY

This study conducted four substudies to provide in-depth understanding on the commercialization process of high technologies. These substudies were published as an article in peer-reviewed journals. Articles 1, 3 and 4 were published by *Technology Innovation Management Review*; article 2 was published in *Academy of Entrepreneurship Journal*. Article 4 was published in a special issue on: *Technology Commercialization and Entrepreneurship*. This chapter presents a summary of these articles.

Table 7: Details of the Study's Articles

	Authors	**Year**	**Title**	**Journal**	**Other details**	**Current status**
1	Al Natsheh, A., Gbadegeshin, S. A., Rimpiläinen, A., Imamovic-Tokalic I., and Zambrano, A.	2015	Identifying the Challenges in Commercializing High Technology: A Case Study of Quantum Key Distribution Technology	Technology Innovation Management Review	Vol. 5 (1), 26–36.	Published
2	Gbadegeshin, S.A.	2017	Commercialization Process of High Technologies: Case Study of Finnish University Spin-off	Academy of Entrepreneurship Journal	Vol. 23 (2), 1-22.	Published
3	Gbadegeshin, S. A.	2018	Lean Commercialization: A Framework for Commercializing High Technologies.	Technology Innovation Management Review	Vol. 8 (9), 50-63.	Published
4	Gbadegeshin, S. A.	2019	The Effect of Digitalization on the Commercialization Process of High technology Companies in the Life Sciences Industry	Technology Innovation Management Review	Vol. 9(1), 49-63.	Published

4.1 Article 1: Identifying the Challenges in Commercializing High Technology

Al Natsheh, A. - Gbadegeshin, S. A. - Rimpiläinen, A. - Imamovic-Tokalic I. - Zambrano, A. (2015) Identifying the Challenges in Commercializing High Technology: A Case Study of Quantum Key Distribution Technology. *Technology Innovation Management Review*, Vol. 5 (1), 26–36.

Considering that high technologies are capital-intensive technologies, there may be other obstacles that facing them, so it is essential to investigate the possible challenges that may confront the ICT industry, which is an important one. The cybersecurity sector of the ICT industry is especially essential, as digitalization keeps advancing (Tihinen & Kääriäinen 2016; Parviainen et al. 2017). Therefore, this article explored the challenges facing the commercialization of a cybersecurity technology. The article was co-authored. This study's researcher is the second author, and he was responsible for drafting the interview and survey questions, and the whole article. He also managed the online survey, transcribing the recorded interviews, and analyzing all the data. He also contributed to the article's revisions before publishing.

The article was developed in relation to the authors' experience. They were aware of several problems facing the high technology commercialization and noticed that there might more challenges at that time. Thus, they reviewed existing works on the commercialization problems and found some identified problems. For example, Parker and Mainelli (2001), Rosa and Rose (2007), and Bulsara et al. (2010), stated that marketing, management, patent filing, motivation, policy, human resources, technology incompatibility and financing were challenges encountered when commercializing high technologies. Likewise, the authors of this article found that some scholars (already listed in the chapter 1 of this dissertation) had examined specific industries, such as bio-pharmaceutical, nanotechnology, food and agriculture, health and medical. They noticed that these scholars concluded that technology transfer, intellectual property (IP), entrepreneurial skills, regulation and legal issues are other commercialization obstacles in addition to the aforementioned general problems. The authors also noted that there were limited studies on the problems facing cybersecurity high technologies and that using the case study method would be plausible, as was suggested by Prebble et al. (2008) and Pellikka (2014).

The article's authors decided to conduct an empirical study with the aim to identify other problems that could confront emerging high technologies and to share their experience. The article used a case study of Quantum Key Distribution (QKD) technology. QKD technology was one of the focused technologies to be commercialized that time by the European Commission. The article asked this

question: *What are the challenges that can hinder successful commercialization of QKD technology*? To achieve its goal, mixed research methods were used, and all the study participants were industry stakeholders across the European Union.

The findings of the empirical study revealed these problems: scattered and small markets, supply chain development, technology validation/certification, lack of available or adequate infrastructure, after-sales services, technical development, customer orientation/awareness and government regulations. The article made theoretical and practical contributions. Theoretically, the article identified more challenges that the existing literature did not state or emphasize. Similarly, the article identified and emphasized that technology validation or certification, unavailability of infrastructure and lack of planning for after-sales services posed obstacles for commercializing high technologies. Practically, the article recommended that potential entrepreneurs, cybersecurity companies and governments should be aware of the new challenges and plan for their mitigation. Despite the article's contribution, it had limitations. It focused on a high technology and it sampled a limited number of study participants. However, its limitations were used to call on the scholars for further studies.

4.2 Article 2: Commercialization Process of High Technologies

Gbadegeshin, S.A. (2017b) Commercialization Process of High Technologies: Case Study of Finnish University Spinoff. *Academy of Entrepreneurship Journal*, Vol. 23 (2), 1-22.

The complexity and heterogeneity of high technologies compel entrepreneurs to employ different commercialization methods (Gbadegeshin 2017a). Spinoff is one of the methods that scholars such as Mustar et al. (2006), Rothaermel et al. (2007) and Evers et al. (2016) argued that it could be used for investigating the commercialization process. These scholars called for a longitudinal study on the commercialization process of the Spinoff. Similarly, the scholars Cooper and Sommer (2016) and Conforto and Amaral (2016) demanded that the application of the Stage-gate model needed to be investigated further on the commercialization process. These situations prompted this study's researcher to embark on an empirical study for this article.

The primary objective of the article was to provide in-depth knowledge on the commercialization process for academia and practitioners. The article asked these questions: i) *How does a University Spinoff (USO) commercialize its high technology*? (ii) *Does the USO follow the stage-gate commercialization process*? and (iii) *Why does the USO succeed in its commercialization adventure*? The article attained its goal by using a case study method. The case study came from the

Cleantech industry and the focus was on the new Cleantech technology. The research instruments used in the article were documentary and participatory observations. This study's researcher is the article's sole author and he was a part of the commercialization team for the case study company between 2013 and 2015. All the stakeholders for the Cleantech industry participated in the article's empirical study. The stakeholder included inventors or innovators, suppliers, customers, government officers and university technology office staff.

The article's empirical study revealed that the entire process of high technology commercialization. The empirical study noted that following the Stage-based model process is not essential. The findings also showed that flexibility is very important for the commercialization process. Several factors, that were responsible for possible success of the commercialization process, were identified and discussed. Among those factors are vision, the parent organization's interest, personal interest and motivation of the inventor or innovator and other stakeholders, the innovators' competence to recognize or create a business opportunity around the technology, the stakeholders' industrial or legal knowledge, and trust, previous positive collaboration, and the commercialization team's working experience. Others factors are networks, good leadership and commercialization team commitment. The article emphasized that the plan should be regarded as a plan that is subject to changes or modifications.

The article contributed to the discourse on the commercialization process and the Spinoff. It emphasizes on the flexibility of the commercialization process. The article also challenged the Stage-gate model by stating that the commercialization process does not need to follow the model strictly. This challenge was not discussed in previous literature. Similarly, the article contributed to the commercialization practice by outlining the facilitating factors of the commercialization process at various phases. These factors provided insight for commercialization teams, technology entrepreneurship educators, engineers and scientists, and companies. Additionally, the article contributed to the methodological approach of commercialization. It used both the documentary and participatory observation methods for its case, which were not previously employed. However, the article was limited by focusing on a single high technology.

4.3 Article 3: Lean Commercialization Framework

Gbadegeshin, S. A. (2018a) Lean Commercialization: A Framework for Commercializing High Technologies. *Technology Innovation Management Review*, Vol. 8 (9), 50-63.

To ease the commercialization challenges and complexities, some scholars such as Apilo et al. (2015), Kruuti (2016), and Gbadegeshin and Heinonen (2016), have suggested that a lean approach could be used to mitigate the problems. In responding to the calls of these scholars, an empirical study was conducted to examine the commercialization activities of high technology companies. Entrepreneurs and their business advisors were interviewed, and their high technologies were observed between 2013 and 2016. The findings showed that these stakeholders employed the lean start-up methodology in their commercialization activities. Although the interviewed entrepreneurs were unaware of the methodology at that time (that was in 2012), the business advisors who were interviewed in 2017 confirmed that experienced or serial high technology entrepreneurs employed the methodology nowadays due to their past experiences in risk-takings. The advisors affirmed that the methodology is presently growing among young entrepreneurs who are influenced by digitalization and making a quick income. This finding was confirmed with the recent work of Hemilä and Jaring (2018) and Shimasaki (2018), who recommended the application of lean startup for commercialization of high technologies.

In relation to those findings, the article proposed a new model, called Lean commercialization that inculcates the lean startup methodology into the commercialization process. The article provides a detailed description of the model's process and application guidelines for the model. Briefly, the model consists of evaluating a new technology, developing prototypes, testing the prototypes, analyzing the test results, and making decisions. Several activities are to be performed at each stage of the model. For examples, technical, IP, and business analyses must be conducted at the evaluation stage; while, technical, market and business models must be performed at the test stage.

The article contributed to knowledge on the commercialization process by introducing a lean commercialization logic. Similarly, it provided a practical guideline for potential users of the theoretical framework, such as technology entrepreneurs, technology-based companies, and entrepreneurship educators. Additionally, precautions for applying the model were given, such as the R&D funding system, entrepreneurship policy, and the infrastructure in the user's country (that might limit the application contextually).

4.4 Article 4: The Effect of Digitalization on the Commercialization Process

Gbadegeshin, S. A. (2019b) The Effect of Digitalization on the Commercialization Process of High Technology Companies in the Life Sciences Industry. *Technology Innovation Management Review*, Vol. 9(1), 49-63.

The desktop research on digitalization showed that there were limited scholarly studies on digitalization as claimed by Henriette et al. (2015) and Parviainen et al. (2017). The research also showed that there were little or no work on how digitalization changes the commercialization process. Thus, this article investigated the following question: *How does digitalization influence the commercialization process of high technology companies in the Life Sciences industry?* An empirical study was conducted in 2017 and stakeholders in the Life Sciences in a region in Finland participated. The stakeholders consisted of entrepreneurs, business advisors, business development manager or directors, innovation managers, senior UTTO officers, and officers from government agencies.

The empirical study revealed that digitalization was initially interpreted as digitization. Meanwhile, entrepreneurs, businesses and academia have now realized that digitalization goes beyond digitization. Likewise, the findings showed that digitalization changes commercialization activities, especially sourcing and managing information, conducting different analyses, performing official activities, big data and routine activities. The findings revealed further that the changes of digitalization led to an iterative commercialization process (theoretical framework). On the other side of the coin, the findings showed that digitalization changes led to the creation of new sets of big data and digital fears (attacks).

The article's theoretical contribution was an introduction of iterative commercialization process model. It also defines new features that distinguish digitalization and digitization terms. It also presents different forms of the digitalization transformation on the commercialization process that were not previously discussed by the scholars. Apart from the theoretical contributions, the article made a practical contribution by highlighting areas in which digitalization transformed the commercialization process. These highlights serve as insights for scientists, technologists, and Life Science companies.

In rounding off this chapter, it can be noted that articles 1, 2 and 4 focused on each selected industry, and article 3 focused on all selected industries. In articles 1 and 2, a single high technology was focused on, but article 3 focused on 25 high technologies. Article 4 focused on the Life Sciences industry, but many technologies were considered because each study participant has knowledge on more than 2 two commercialized technologies. Hence, the articles of this study provide a better understanding of the commercialization process in the studied context (or industries).

5 DISCUSSION AND CONCLUSION

Having explained the theoretical background, research process and supported articles, this chapter presents and discusses the findings of the study. Additionally, it outlines the theoretical and practical contributions, challenges, and limitations of the study. Proposals for future studies are also presented in this chapter.

5.1 Integrative Commercialization Process Model

The foremost relationship among the previously discussed theories, theoretical frameworks and model is that they all considered *innovation* as the main foundation and backbone of their processes. They also considered radical invention, which makes their focus highly relevant to the high technologies. Furthermore, they all considered the market as the final place where the outputs of their process would be justified. Thus, the first finding of the current study is that the commercialization process models are rooted in the TAM, UTAUT, Stage-gate, Effectuation, Bricolage and Lean Start-up theoretical frameworks. Similarly, the current study notes that these frameworks employed a mixture of linear and non-linear logic. Analytically and theoretically, this finding provides insight into the logic of the commercialization process model.

The second finding is based on empirical results from the ICT, Cleantech and Life Sciences industries. The finding shows that the high technology commercialization process starts during the pre-innovation phase, which is highly considered in the NPD, Spinoff and TOT fields. Specifically, Robbins and O'Gorman (2014), Perry-Smith and Mannucci (2015), and Pereira et al. (2017) explained that the pre-innovation deal with R&D activities of the innovation process. Surprisingly, this finding reveals that the commercialization process often starts from an *idea*, which often emerges from continuous R&D activities (see: Gbadegeshin 2017b; 2018a; 2019b). Although the above-mentioned innovation scholars explained that innovation emerges from R&D activities, they have not explained the roles of *continuou*s R&D on the innovations. This finding also reveals that the *idea* is mostly influenced by environmental factors consisting of economic, social, political, technological and legal activities. Changes in these factors give direction to the idea development. The influence of environmental factors was not explained by the above-mentioned pre-innovation scholars. The finding further reveals that the idea often becomes an invention. The finding

shows that when the invention emerges, commercialization activities start, and it demonstrates that these commercialization activities are commonly done in the selected industries: assessing value, market needs, IPs, government regulations and policies, competition, related technologies, existing infrastructure, related supply chain and standardization issues of the invention (see: Al Natsheh et al. 2015; Gbadegeshin 2017b; 2018a; 2019b). It also reveals that when the results of the above assessments are positive, the invention becomes an innovation. The finding pinpoints that, when innovation emerges, information about it starts to emerge via patent filings, scientific publications, news reports and, nowadays, internet promotions through websites (especially from the organization that produced the idea). This phase is referred to as *diffusion* according to the scholars of innovation theories (e.g., Rogers 2003; Hoffmann 2011). In a nutshell, the second finding also provides an insight into the commercialization process logic.

The third finding reveals that when an innovation is diffused, the commercialization process is more pronounced by the commercialization teams, and the commercialization activities of this phase are similar to the R&D and prototyping of the innovation theoretical frameworks; business case and development of the NPD model and development of the product/service of the entrepreneurship theoretical frameworks; assessment, protection and prototyping of the Spinoff theoretical framework; the development stage of the TOT theoretical frameworks, and stages 3 and 4 of the commercialization process models. These activities are grouped as pre-commercialization in the empirical studies (see: Gbadegeshin 2017b; 2018; 2019b) and is also noted by Gübeli and Doloreux (2005). Despite the fact that all the aforementioned commercialization process models have similar pre-commercialization activities, this finding notes that they did not consider them to be a commercialization process. The above-mentioned scholars of the innovation, NPD, TOT and Spinoff considered the pre-commercialization activities as further development of new technologies. Surprisingly, these scholars considered the role of marketing at this phase, but the marketing scholars did not offer any strategies and tactics for this phase. Now, if these scholars of innovation, NPD, TOT and Spinoff did not regard their development activities as a commercialization process, this question should be asked: *Why do they need further development of technology when its business is ignored*? The underpinning motive for further development of any new technology is definitely to make the new technology marketable, adoptable, acceptable and sometimes useful for society. Therefore, technology development activities should be regarded as pre-commercialization. This finding provides more insight into the commercialization process.

The fourth finding shows that the theoretical frameworks and models employed in this study defined some commercialization activities. However, the finding reveals that the roles of internal discussion and communication, infor-

mation, regulations, skills, funding, networking, internationalization and feedback are essential and should not be kept as salient activities as they are presently treated in NPD, TOT, Spinoff and commercialization models. This finding provides more knowledge about the commercialization process.

The fifth finding shows that the theoretical frameworks from the selected fields has not yet included changes of digitalization on their commercialization phase. Similarly, the finding reveals that not all the theoretical frameworks considered the importance of decision making for selecting the commercialization methods. The finding reveals further that decision on the commercialization method is essential, because it affects the marketing strategies and tactics that are recommended by the marketing scholars. The finding also shows that the commercialization process has post-commercialization activities. Although the sixth generation of the innovation theories as well as NPD, entrepreneurship, Spinoff, TOT and marketing considered post-launching activities; meanwhile, these fields did not explain that the post-commercialization outcomes often lead to incremental or radical innovations as the current findings have shown (see: Gbadegeshin 2017b; 2018a). This finding gives insight on the commercialization process.

Lastly, the current study found that the outputs of the commercialization process are not only products and services but also solution packages. This finding shows that the solution package is not considered in the innovation, NPD, Spinoff, and TOT models. Similarly, this finding shows that the commercialization activities from the pre- to post-commercialization phases are flexible and iterative due to the changes of digitalization. The finding shows further that some activities of the commercialization phase are performed during pre- and post-commercialization (see: Gbadegeshin 2017b; 2018a; 2019b). This finding pinpoints that the commercialization process is not fixed but flexible and highly depending on commercializing high technology, the development stage of the commercializing firm, the skills and experience of the commercializing team, and type of the industry. This finding provides insight on the commercialization logic.

Based on the above findings, it can be argued that the commercialization process is not the last phase of the innovation, NPD, Spinoff and TOT processes, but it is a part of the entire process from idea to post-consumption of the idea (after being processed to product, service and solution packages). Similarly, the above results demonstrate that, when studying the commercialization of high technologies in ICT, Cleantech and the Life Sciences, the above-mentioned theories are not completely applicable, but they need to be adjusted. It can be also argued that there is a need for improvement on the theories, theoretical frameworks and models for the selected fields. With these arguments, it can be agreed that a new commercialization model is needed as noted by Kahn et al. (2006), Datta et al. (2013), and Aarikka-Stenroos and Lehtimäki (2014), who called for an integra-

tive approach. The argument of these scholars is that existing commercialization models must reflect the realities of the process and consider companies in different industries, because commercialization nowadays entails many institutions. With respect to the arguments, a new commercialization model is hereby introduced – ***Integrative Commercialization Process***. The ICP model was developed by taking the existing frameworks in the selected industries and modifying them to suit the context. Hence, the ICP is a contextualized model for ICT, Cleantech and the Life Sciences industries. Figure 9 shows I and presents its details in the following subsections.

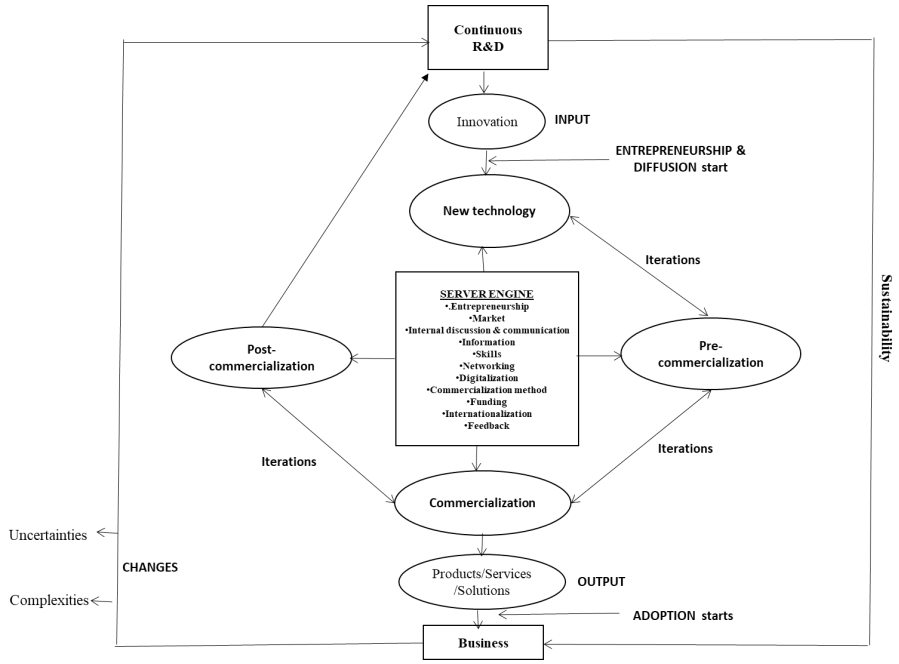


Figure 8: Integrative Commercialization Process for ICT, Cleantech and Life Sciences

5.1.1 Description of ICP

The ICP starts from *Continuous R&D*, which is a term used to denote the continuousness of the pre-innovation activities. One of the outcomes of continuous R&D is *Innovation*. Thus, continuous R&D leads to innovation. This innovation serves as *Input* for new technology. Making use of innovation for the new technology is propelled by *Entrepreneurship*. The actions of entrepreneurship lead to *Diffusion*. During diffusion, several pre-commercialization activities are done, such as seeking interest and obtaining a commitment from stakeholders, identifying industrial or business application area(s), analyzing the market and protec-

ting the technology. Thus, the *New technology* phase is a composition of entrepreneurship, the market and a few parts of pre-commercialization. The new technology phase is influenced by the *Server engine*, which refers to the following elements: internal discussions and communication, information, market analysis, regulations, skills, networking, funding, internationalization, feedback, digitalization, commercialization and entrepreneurship. These elements are continuous activities that need to be performed by the commercialization team, for example, [continuous] smooth communication with the commercialization team and other stakeholders.

The new technology phase leads to the *Pre-commercialization* stage, in which the aforementioned pre-commercialization activities are done fully. Other activities to be done are analyzing related IPs, technicalities, regulations and available resources; forming a team; defining the commercialization method; and outlining possible challenges and opportunities. Notably, the arrow between new technology and the pre-commercialization stages denotes that both phases are iterative. Similarly, pre-commercialization is influenced by the elements of the server engine.

The next phase is *Commercialization*. The following activities are done at this stage: defining the target market, visiting market stakeholders, defining and developing business models, planning the supply chain, developing prototypes or samples, testing prototypes or conducting preclinical tests or experimentation by users, obtaining reference sales or customer commitments, undertaking official procedures, acquiring more funds and finalizing the commercialization method to be used. At this phase, Products or Services or Solutions could be manufactured, and they are regarded as Output of the commercialization process. Additionally, a new business or business unit can be established. Sometimes, the service center can be established if the output benefits society. Thus, commercialization leads to *Business*. Meanwhile, before Business emerges, *Adoption* needs to take place; thus, adoption starts during the commercialization phase and leads to Business. Notably, continuous R&D leads to Business, and the link between them denotes *Sustainability*. This means that a business is sustainable if it could continue with its new innovations. The pre-commercialization and commercialization phases are iterative.

The following phase is *Post-commercialization*. The activities to be done are: selecting a business model, planning and managing production, managing customers, suppliers, financiers and other stakeholders, and managing internationalization. These activities often lead to continuous R&D. The primary reason for this is that feedback and experience of the commercialization team often make them propose a new product or service or solution to support their new business. Their proposal can lead to new innovations or modifications to the existing innovations.

Lastly, Business is affected by external factors, specifically *Uncertainties* and *Complexities*. These factors are termed *Changes*. The changes make R&D continuous. Thus, continuous R&D is directly influenced by post-commercialization and its changes.

5.1.2 Features of ICP

The main features of ICP are continuous R&D, server engine, commercialization phases, flexibility and iterations, changes and sustainability. The continuous R&D is noted in the work of Mohr et al. (2005), Amadi-Echendu and Rasetlola (2011), and Conforto and Amaral (2016). Meanwhile, the articles of the current study, Al Natsheh et al. (2015) and Gbadegeshin (2017b; 2019b), pinpoint that R&D activities are continuous for developing and commercializing high technologies. The Sever engine distinguishes ICP from the existing models. For example, smooth communication between the commercialization team and the external collaborators are essential as it was shown in the case study of Gbadegeshin (2017b), as well as Nevens et al. (1990) argument. Another example, searching and analyzing information, is essential in this digital age. Digitalization has made information readily available but selecting and analyzing the information is crucial for the commercialization team. This activity is established in the empirical findings of the current study (see: Gbadegeshin, 2017b, 2019b). Similarly, the current findings reveal that familiarization with rules and upcoming policies is an important task for the commercialization team. Likewise, networking has been a paramount commercialization activity, as established in the work of Aarikka-Stenroos and Sandberg (2012), Al Natsheh et al. (2013b), and Gbadegeshin (2017b; 2019a). Funding and internationalization are also established as a business activity, which numerous scholars have discussed, such as Feldman et al. (2002), Powell (2010) and Al Natsheh et al. (2013a). Feedback is well researched, especially with the Lean start-up method. The scholars, such as Furr et al. (2014), Gbadegeshin and Heinonen (2016) and Gbadegeshin (2017b; 2018a) have stated that receiving and analyzing feedback facilitate the commercialization process.

Other features of the ICP model are *flexibility* and *iterations*. Flexibility in this model refers to the arrows denoting that any of the activities of each phase can be performed at any phase. Similarly, it denotes that the execution of activities depends on the nature of the commercializing high technology, its target market and similar factors; the activities are not fixed to any phase. In fact, these activities can be performed concurrently, or some can be postponed as the situation might be demanded. The activities are situation- or condition-based. Moreover, iteration in this model means that the outcome of the commercialization activity

determines its direction for the commercialization team. For example, if IP analysis revealed that the new technology would be restricted in a certain product form (design), the team could decide to redesign the technology in another form. Similarly, if a market analysis showed that the new technology could not be useful in the initial target market, a new market or segment could be tried. The roles of flexibility and iterations are well established in the work of Aarikka-Stenroos and Lehtimäki (2014), Cooper (2014, 2016) and Conforto and Amaral (2016).

The ICP model shows that a business seems to be established from the commercialization phase (Figure 9). Thus, post-commercialization supports the *sustainability* of the framework for survival, as Klofsten (2010) proposed in the business platform model.

5.1.3 Activities of the ICP

The ICP model proposes some activities to be performed at various commercialization phases. The activities are developed from this study's findings. For the ***pre-commercialization*** phase, the most important activity of this phase is assessing the required commercialization skills. According to Gbadegeshin (2019a), having commercialization skills is imperative for high technology entrepreneurs. The scholar argued that the commercialization skills, which include presentation or pitching, regulation, information analysis, and negotiation, are essential for acquiring and managing relevant resources for the commercialization. Another important activity of pre-commercialization is identification of the market(s) for a new technology. This is pinpointed by Klofsten (2010) and Al Natsheh et al (2013a, 2014, 2015). Supportably, Gbadegeshin (2018a) found that identification of a business application for a new business is a lean commercialization activity employed by high technology entrepreneurs nowadays. Therefore, an ability to identify industrial applications of a new technology is essential.

Additionally, seeking and obtaining interest and commitment from internal stakeholders is also an important activity at the pre-commercialization phase. Many previous works like Franklin et al. (2001) and Meyer (2003) have noted the significant roles of inventors or innovators. Similarly, Vohora et al. (2002) Yencken and Gillin (2002), and Hindle and Yencken (2004) explained the important roles of innovators towards commercialization, especially their attitude. However, these scholars did not specify the essence of seeking and obtaining the commitment of the inventor, innovator and other stakeholders. During a Spinoff commercialization analysis, Gbadegeshin (2017b) found that the interest of innovators and other stakeholders such as management, colleagues, and funding institutions contributed to the progress of commercialization process. The same result was also noted by Gbadegeshin (2019b).

Moreover, Al Natsheh et al. (2015) stated that infrastructure could be an obstacle when commercializing high technologies. The scholars recommended that examining the supporting amenities for utilization of a new technology is important. The recommendation of these scholars seemed to be highly relevant for modern technologies that are interconnected with digitalization, as Gbadegeshin (2019b) noted, and inter-industrial as DeTienne and Koberg (2002), Tremblay and Yagoubi (2017) and Yan et al. (2017) explained. Similarly, Gbadegeshin (2017b) stated that regulation changes made the commercialization of his case study technology succeeded. Hence, defining the possible infrastructure, challenges and changes is an important activity at the pre-commercialization phase. This activity is related to analyzing government policies.

There are other activities that are also important for the pre-commercialization phase but to varying degrees. Amongst them are evaluating the technicalities of the new high technology, protecting the technology, forming a commercialization team, and defining the commercialization method(s). These activities change the commercialization process. For example, Gbadegeshin (2017b) found that the production strategy of his case study changed due to the customers' preferences. This change led to technical issues that the case study company was able to manage with its initial technical analyses. This activity is echoed by Bradley et al. (2013) and Al Natsheh (2014). In another example from Gbadegeshin (2017b), the case study company had a challenge with its IP, but it managed the problem with its technical analyses. Maine and Garnsey (2007) and Pietzsch et al. (2009) argued that protecting new technology should be done during commercialization process in order to be secured. Their argument is understandable and important, especially during this digital age where uniqueness is significant for competition. Forming a team with business and technology expertise is an important tool for commercialization process, as found in the case of Gbadegeshin (2017b; 2019a). Similarly, defining the commercialization method is an essential commercialization activity. Although many scholars like Kascha and Dowling (2008), Aggarwal and Hsu (2009), Festel (2013), and Battistella et al (2015) have highlighted that there are many methods of commercialization, selecting the appropriate method facilitates the commercialization process, according to Gbadegeshin (2017a), and as it is shown in the case study of Gbadegeshin (2017b) and Gbadegeshin and Heionen (2016).

For the ***commercialization*** phase activities, they appear to be common to business development in the high technology industries according to Maine and Garnsey (2007) and Pietzsch et al. (2009). Similarly, Klofsten (2010) and Gbadegeshin (2017b; 2019a; b) discussed the roles of the activities. For instance, Gbadegeshin (2017b) showed how the case study company defined its target, visited and discussed with market stakeholders, developed and modified its business model, developed and tested prototypes and started its sales. Gbadegeshin

(2018a) also noted these activities for the lean commercialization theoretical framework. And for the ***post-commercialization*** phase, the activities represent feedback and concrete effort to grow the newly established business as well as keep the business sustainable. Gbadegeshin (2017b; 2019b) noted that the post-commercialization activities represent an effort to make a new business concrete. The following Table 8 shows summary of the activities for each phase.

Table 8: List of ICP Activities

Pre-commercialization	Commercialization	Post-commercialization
Seeking interest & obtaining commitment	Defining the target market	Selecting the business model
Assessing available skills	Visiting market stakeholders	Planning and managing production
Identifying industrial / business application area (s)	Defining and developing business models	Managing customers, suppliers, financiers and other stakeholders
Analyzing the market	Planning the supply chain	Managing internationalization
Analyzing IP	Developing prototypes / samples	
Analyzing technicalities	Testing prototypes/ conducting preclinical tests / experimentation by users	
Analyzing regulations	Obtaining reference sales or customer commitments	
Analyzing available resources	Undertaking official procedures	
Protecting the technology	Acquiring more funds	
Forming a team	Finalizing the commercialization method	
Defining the commercialization method		
Defining possible challenges and opportunities		

5.1.4 Theoretical Assumptions of ICP

First, ICP assumes that the commercialization process should be regarded as a business process. It considers commercialization as a business development, but it does not emphasize that every commercialization project should or would lead to establishment of a new business entity. It emphasizes that the main objective of any business, which is to make returns on investments, should be pursued during the commercialization process. Similarly, ICP assumes that considering the commercialization process as business process would cause potential entrepreneurs to have a business orientation from the beginning of their commercialization projects. Having a business orientation is a prerequisite for a successful

commercialization (Hindle & Yencken 2004; Gübeli & Doloreux 2005; Farsi et al. 2014).

Additionally, ICP assumes that if small business firms and intrapreneurs could regard the commercialization process as business process, they would be able to manage the process more effectively and efficiently. With proper management, they would be able to market their new technologies cost effectively and mitigate the risks and uncertainties. Notably, intrapreneurs refer to individuals who act as entrepreneurs in organizations, especially large companies (Luchsinger & Bagby 1987; Carrier 1996; Teltumbde 2006). Furthermore, ICP assumes that treating the commercialization process as a business process would enable commercialization teams to be flexible and agile in their process. This assumption is based on the work of Brettel et al. (2016) and Hemilä and Jaring (2018), who emphasized that flexibility is important for business activities. This assumption is also emphasized in the work of Cooper (2014; 2016), Shimasaki (2018) and Gbadegeshin (2018a) in relation to commercialization. Based on the above assumptions, ICP assumes further that the high technology commercialization should be treated as a high technology business or firm.

To conclude, the development of the ICP model is an important outcome of this study. The details of the ICP model show that the model combines different theories, theoretical frameworks, models, aspects, factors, technologies and industries of high technologies. It satisfies the model proposition criteria recommended by Loch and Kavadias (2007), which include generation, selection, transformation and coordination. The ICP model shows how an idea emerges, its process to innovation as well as its process to final solution. It also shows the coordination and implementation of the activities of the various stages of the processes. Therefore, it represents the reality of high technology complexities and complications. Hence, it is hoped that the ICP model would enable scholars to compromise on an integrative approach for the commercialization process discourse, as suggested by Maine and Garnsey (2006), Pellikka (2014) and McCoy et al. (2008). Similarly, it is hoped that the ICP model would facilitate the commercialization process because of being flexible, adaptive and agile. as Harrer, and Smith (1987) argued that the conversion of new technologies to consumer goods and services would be easier when their processes are integrative.

5.2 Answering Research Questions

Commercialization of high technologies is very important to research institutes, business organizations and national economies. These technologies require huge investments for their development; hence, if they are not commercialized, their investment might not yield any returns. However, if they are commercialized,

they generate returns on investment and most importantly, they are useful for society. Their commercialization provides another source of income for the research institutes (including universities) which are presently facing shortages of funds and pursuing entrepreneurial university. Similarly, the commercialization of high technologies supports the sustainability of business enterprises. Currently, sustainability of businesses is essential for every nation, and being competitive is crucial for enterprise sustainability (Ulrich & Eppinger 2011; Kahn et al. 2013; Al Natsheh et al. 2015). Commercialization of high technologies of the enterprises is one of the means to attain their sustainability. Furthermore, these scholars, Baptista and Preto (2009), Banerjee and Cole (2011), and Schrier and Hallin (2017), have established that commercialization of high technologies contributes to national economic development.

Given the importance of commercialization of high technologies, this study found it essential to contribute to the body of knowledge about the commercialization process. The study aimed ***to investigate how high technologies are commercialized, especially in ICT, Cleantech and the Life Sciences***. In attaining this aim, the study employed an integrative approach by considering the commercialization process of interconnected industries and examined interrelated fields of study. This approach facilitates the commercialization process in two ways. The first way is that it makes the commercialization process flexible, adaptive and agile. The scholars Mohr et al. (2005), Solberg et al. (2008) and Aydalot and Keeble (2018), established that the high technologies are expensive, resource intensive and time consuming with high level of risks and uncertainties. Risselada et al. (2014) and Chanda and Das (2015) added that commercializing them would allow them to generate a return in a short time. To commercialize them cost effectively and efficiently, they need an agile and flexible process, as, Brettel et al. (2016), Gbadegeshin (2018a) and Hemilä and Jaring (2018) recommended. Hence, an integrative approach allows agility, flexibility, and adaptation to be attained. The second way is that it enables the commercialization team to have a business orientation. According to Gübeli and Doloreux (2005) and Farsi et al. (2014) and Gbadegeshin (2017b), business orientation of commercialization team facilitates the process. These scholars recommended that the team should have business people as members so that they could inculcate business perspectives into their commercialization process.

With the integrative approach, this study asked three RQs to achieve its objective. The first question was: ***What are the challenges of the commercialization process of high technologies?*** This question was motivated by a popular quote from Charles Kettering, who said that: *a problem well stated is a problem half solved*. The practical experience of the researcher of this work made him understand that a problem would pave the way for different possible solutions or better ways of managing the problem. This was initially raised by the scholars Harrer

and Smith (1987) and Chiesa and Frattini (2011), who called for further studies on the challenges of commercialization. Thus, article 1 focused on the problems facing the commercialization of high technologies. The article affirmed that the general problems associated with the market, management, technology and legalities posed obstacles to the commercialization process. The article also showed that certification of new technology, infrastructure to support the new technology and after-sale services were new challenges facing the process. Although this article focused on the QKD technology, which belongs to ICT, article 2 also noted these three challenges when the commercialization team encountered them. These problems led the team of the article 2 to make changes in their commercialization plan. In addition, article 3 made reference to the above problems and recommended that commercialization teams should consider infrastructure in applying lean commercialization logic. Similarly, article 4 also noted that having knowledge of regulations and related policies is essential for high technology entrepreneurs, because their new technologies might be constrained with incoming new rules. This observation created a business opportunity for the article 2 case study company.

Furthermore, the innovation scholars, such as Kotsemir and Meissner (2013) and Barbieri and Alvares 2(016), stated that different innovation generation theories were developed due to economic challenges. These scholars affirmed that the new theories were proposed in order to solve economic problems facing the innovation at that period. Similarly, it is also noted that the innovation theories employed a certain logic (linear or non-linear) due to the prevailing economic situations. Additionally, the Stage-gate frameworks of NPD was developed as an effort to solve failures in the innovations. Meanwhile, these economic conditions can only be known when the problems are well identified. Therefore, having knowledge about the various commercialization problems provide better understanding of the commercialization process.

The findings of this study demonstrate that each selected industry had its own specific challenges in facing its commercialization process. For the ICT industry, constant changes in technologies, the need for new infrastructure, marketing and certification seem to be the critical challenges confronting the commercialization processes. For the Cleantech industry, new government policies, the technicality of its technologies, marketing, and the understanding and preferences of their customers appear to be the main problems facing their commercialization processes. And for the Life Sciences, new government rules, new results of the basic research, lack of commercialization skills and a need for infrastructure seem to be the primary obstacles of the commercialization process. Having knowledge about these problems would facilitate the commercialization process of these industries.

When the challenges were identified, the second question was: ***What are the commercialization processes and their enablers in high technology industries?*** This study's researcher moved forward by investigating the commercialization processes. This is shown in article 2, in which a commercialization process was studied for 3 years. The article disclosed the entire process and provided knowledge on the importance of flexibility and different enabling factors. Similarly, it is shown in article 3 where commercialization activities of many high technologies were observed for 3 years. The article also proposed a new commercialization process logic. The logic considered previously identified problems, factors and different technologies from the selected industries. This logic showed how the process could be flexible and agile. The article also showed how the logic could be used for different technologies and a practical guide was provided. The main outcome of examining the process shows that the process has stages, but these stages are not fixed. The stages are flexible, and they depend on nature of the technology and the target market. The outcome also shows that there are several activities that are flexible. These activities can be performed at any stage depending on the situation of the commercializing high technology. The recent versions of theoretical frameworks and models employed in the current study show that any new frameworks should be flexible, agile and adaptive for the commercialization process.

In respect to the answers to RQ2, the ICP model was created in order to inculcate flexibility, agility and sustainability for the studied industries. It also considers possible enabling factors from these industries. The stages of the model are iterative. The ICP employs a mixture of linear and non-linear logic, especially lean commercialization logic, and thus, it serves as a framework that depicts the contextual commercialization process of ICT, Cleantech and the Life Sciences. Therefore, having knowledge of the commercialization process from different industries enables an in-depth understanding of the process in the studied industries.

Knowledge acquired from the second question led to the third question: ***How does digitalization change the commercialization process of high technologies?*** This study's researcher noticed that digitalization was affecting human activities. He noticed it during his observations for the article 2 and 3. Thus, he decided to examine how it changed the commercialization process, especially from a highly regulated industry, Life Sciences. This investigation broadened the knowledge that commercialization skills, which were previously known, were insufficient with the advent of digitalization. Article 4 showed that digitalization made the commercialization process simultaneous, flexible and, to some extent, iterative. Conversely, the article revealed that digitalization increased the commercialization teams' workload, creating new sets of big data (where current data are not utilized optimally) and increasing vulnerability to cyber-attacks. Additionally,

the article also showed that there is a difference between digitization and digitalization. Investigating the changes of digitalization made this study up-to-date, because this issue had not yet been discussed in regarding to the commercialization process.

Although the Life Sciences were the focus, acquired knowledge from the ICT and Cleantech industries shows that digitalization is changing their commercialization processes. The ICT industry, which is the main origin of digitalization, also changes with it. The industry is experiencing a rapid increase in new technologies, especially digital technologies. This situation demands that the commercialization process of the industry needs to be agile and flexible in deploying the new technologies. Similarly, Cleantech is changed by digitalization, especially in the area of *efficiency* and *effectiveness* of the new technologies. Hence, it can be deduced that digitalization is changing the selected industries. These digitalization changes were considered in the ICP model. The model regards digitalization as an important factor that needs to be considered throughout the entire commercialization process. Therefore, consideration of digitalization transformations is important—it is even a prerequisite—for future studies.

5.3 Discussion and Theoretical Contributions of the Study

Commercialization of technology is one of the business research areas that is often discussed in the innovation, NPD, entrepreneurship, Spinoff, TOT and marketing literatures. Hence, there are several studies on the technology commercialization process. Most prior studies focused on different aspects of the technology commercialization process. Some discussed the methodology of the process, otherwise known as *technology transfer*, such as Feldman et al. (2002), Lee (2010), and Gbadegeshin (2017a). Others have explained the enabling factors of the process (e.g., Palmberg 2006; Marx et al. 2014; Kirchberger & Pohl 2016). The strategies of the process are also discussed in the work of, Chen et al. (2011) and Marx and Hsu (2015). However, examining the high technology commercialization process specifically from a multi-industry context and with an integrative approach seems to have been missing. Meanwhile, Pellikka (2014) and Aarikka-Stenroos and Lehtimäki (2014), among others, have called for an integrative approach. By studying the commercialization process of high technologies in the ICT, Cleantech and Life Sciences, the current study provided new insights from these industries as well as from the selected theoretical fields that were used to gain a better understanding of the process.

Previous works on the commercialization process revealed that different theories and frameworks were employed to discuss the process. Meanwhile, the current study shows that those theories and models could be combined at various

stages to explain the commercialization process of high technologies in the studied sectors. The following paragraphs present how the existing theories and frameworks could be used to discuss the commercialization process, especially in the contexts of the ICT, Cleantech and Life Sciences industries.

Innovation theories

The assumption that commercialization is the last phase of the entire process needs to be reconsidered. The empirical findings of the current study reveal that the commercialization mindset begins when an idea proves to have some value. The value in this study refers to benefits and solutions for existing or imagined problems. Hence, with this mindset, this means the activities and steps toward realizing that value denotes the commercialization process.

The theory of Adoption-diffusion needs to be separated. The theoretical assumption of the diffusion theory states that information on innovation should be spread out so that new technology could be adopted. If this assumption needs to be upheld, the theory is applicable when the commercialization process starts (not at the end of technology development). As explained in the ICP, the commercialization process starts when an invention is confirmed (or becomes an innovation). Hence, the theory of diffusion can be employed at that phase. In the same view, the theory of adoption is applicable when a technology is launched. The theoretical assumptions of the theory show that it deals with the readiness of a new technology, not an innovation that the theory claimed to be tested. By separating the adoption-diffusion theory, the Technology Acceptance Model (TAM) and the Universal Technology Adoption and Use Theory (UTAUT) frameworks would be more relevant and applicable to modern high technologies from the ICT, Cleantech and Life Sciences industries.

Furthermore, the innovation frameworks need to inculcate uncertainty and complexity into their processes. Previous innovation models were silent on the uncertainty and complexity of the process. Although these issues were heavily discussed in the explanations of the frameworks, the current study put them forward to make the frameworks reflective. This effort was initiated with an argument that a framework should be an abstract replica of reality, as Nelson and Winter (1977) argued: *a theory must be wide enough to encompass and link the relevant variables and their effects, and strong enough to give guidance as to what would happen if some of these variables changed* (p. 36).

Additionally, the innovation theories need to include roles of entrepreneurship in their processes. It is noted that innovation processes have been explained for decades, but limited attention has been paid to entrepreneurship roles. Of course, entrepreneurship is a wide field, but an entrepreneurial orientation is essential, as the empirical findings of the current study have shown. Logically, there would be no process if there were no person or group of persons to plan, execute and cont-

rol the activities associated with the process. Such a person is often characterized by an entrepreneurial mindset (and features, as shown in the creative process theories).

The innovation theoretical frameworks need to include the solution in their end-result. One of the criticisms of the innovation frameworks is that they are product-oriented. This is understandable because these frameworks focus on radical and disruptive technologies. Yet, a physical product might not always be the end-result of the innovation process. The empirical findings of this current study show that there are some high technologies that are part of heavy equipment and some that must be offered for consumers as a solution package. Thus, it is important for a new innovation generation model to look beyond products.

Lastly, Rothewell (1994) states that the roles and changes in ICT, along with a lean approach, led to the fifth generation of innovation theory, and pinpoints that the 5G process is essentially one of lean innovations (p. 23) and the key aspects of the process are: integration, flexibility, networking and parallel (real-time) information processing (p. 25). However, the scope of ICT during that time has expanded for decades. Digitalization contains more than the internet, websites and simulations. Therefore, this study contributes to innovation debates by arguing that different forms of digitalization must be considered for a new innovation theory.

NPD, Spinoff and TOT Theoretical Models

The Stage-gate model, which is the background of the NPD, Spinoff and TOT fields, has been improved with the effort of Cooper (2014; 2016; 2017). However, the Stage-gate theoretical framework does not seem to consider the roles of entrepreneurship, the end-results of innovation, and digitalization. Although the model did show the importance of the entrepreneurial mindset from the work of Veryzer (1998), an entrepreneurial orientation is missing in the original theoretical framework of Cooper (1990) and recent versions (Cooper 2014; 2017). Similarly, the model seems to be product- and service-oriented with less focus on solution packages. The current study reveal that, if the framework could inculcate the roles of entrepreneurship and a solution package, it would be suitable to commercialize high technologies from ICT, Cleantech and the Life Sciences.

Entrepreneurship theories

Despite the fact that the entrepreneurship theories were propounded for decades, they also seem to be applicable to the commercialization of modern high technologies. However, these theories need to inculcate digitalization. Similarly, the findings of the current study reveal that commercialization skills are needed to improve the entrepreneurial mindset of potential high technology entrepreneurs from the studied industries.

Marketing strategies

Although marketing theories were not focused during the current study's empirical research, it was learned that the marketing scholars of high technology have not yet considered marketing strategies for the pre-commercialization phase. According to the popular marketing tactics proposed by Beard and Easingwood (1996), most of the marketing strategies and their actions focus only on the commercialization phase. Only a few that considered pre-commercialization were focused on *licensing*. According to Gbadegeshin (2017a), licensing is one of the commercialization methods. Meanwhile, there is a need to provide marketing tactics for the pre- and post-commercialization phases.

In summary, the above theoretical insights provide information for the scholars in those fields and probably show which direction the commercialization discourse could follow. Similarly, the ICP shows that the commercialization process starts from the beginning of NPD, Spinoff and TOT. The process continues in a circular direction. Thus, the ICP model employs mixed logic, which makes it flexible, agile, accelerative and reflective. Lastly, the ICP model considers the entrepreneurship mindset, internationalization, funding, and digitalization, which often affect the NPD and TOT processes. Therefore, the ICP model confirms the recent works of Cooper (2014; 2017) and Conforto and Amaral (2016), who argue that the commercialization process should be flexible, reflective, adaptive and accelerated. The ICP model also confirms that commercialization activities should be performed simultaneously (in parallel). Table 9 shows an overview of the theoretical suggestions.

Table 9: An Overview of Theoretical Contribution

	Innovation		NPD, Spinoff &TOT	Entrepreneurship
Primary theory	Adoption-Diffusion		Stage-gate	Creative process
Specific theory	TAM	UTAUT		Bricolage, Effectuation & Lean Start-up
Previous assumptions	Perceived ease of use & perceived usefulness of technology	Performance expectancy, effort expectancy, social influence, facilitating conditions and personal characteristics determine technology acceptance	Any new product emerges from an idea; the idea needs to be examined at various phases; there are several factors; the process is not "that" linear, but there are various "bus stops" and the user of the new product is important and must be focused on.	The entrepreneurship process is non-linear and iterative
THE COMMMERCIALIZATION PROCESS OF HIGH TECHNOLOGIES IN ICT, CLEANTECH & LIFE SCIENCES				
New Insights	Diffusing message should be started when innovation is confirmed, and the message should be focused on "solutions." Consideration of digital tools is essential.	(i) The nature of technology determines its acceptance factors (ii)The theory should be applied when a technology is launched.	Commercialization starts when an innovation is confirmed; an entrepreneurial mindset is a key to the process; digitalization is an important factor to be emphasized during the process.	(i) An entrepreneurial mindset is the first element to be established before applying any entrepreneurship logic. (ii) Commercialization skills facilitate the process.
Empirical findings (from this study)	Several factors determine technology acceptance, e.g., new policy, availability of infrastructure, availability of substitutes, and nature, sender and extent of diffusing message.	Several factors determine technology acceptance, e.g., new policy, availability of infrastructure, availability of substitutes, and nature, sender and extent of diffusing message.	(i)The process is iterative, flexible, agile, accelerative and reflective. (ii)The roles of an entrepreneurial mindset, funding, internationalization & digitalization are important	(i) An entrepreneurial mindset is one of the key drivers for commercializing high technologies. (ii) Digitalization can change the mindset.
Relevant articles (s)	1, 2	1, 2	2, 4	2, 3, 4

In respect to the above confirmations and Table 9, the current study argues that the commercialization logic is a mixture of linear and non-linear logic, especially in the ICT, Cleantech and Life Sciences industries.

5.4 Practical Implications

The current study provides insights from the studied industries. This study highlights the challenges that these industries are having or that they might be facing soon in their commercialization processes. One of the challenges is *changes*. The current study notes that there is an increase in the change of technologies, government policies, customers' needs and digitalization. This study also notes that these changes are rapid and require a flexible and agile commercialization model

and team. Another challenge is infrastructure. The current study found that the new high technologies sometimes need new infrastructure. Normally, if such an infrastructure is not capital-intensive, the challenge might not be severe. On the other hand, if the infrastructure requires a large investment or a change in government policies, this challenge is severe, and it might delay the commercialization process of the new high technology. Additionally, the commercialization skill or competence of the team poses a challenge for the commercialization process of these industries. The current study found that commercialization competence, business orientation and entrepreneurship mindset play important roles in commercialization processes. Thus, it is imperative for any team in these industries to have someone with a commercialization skill. All these challenges are explained in the current study, and they are well described in the ICP model of the study. Thus, information on the challenges is an insight into this study.

The study also explains the entire commercialization process and outlines different factors that support or hinder it. It also provides possible commercialization logic and knowledge to be used. These pieces of information are an insight for the stakeholders of the studied industries. Similarly, the information is useful for current and upcoming innovators and inventors, entrepreneurs, entrepreneurship educators, research institutes and companies. Furthermore, the ICP model provides insight into the commercialization process logic and knowledge for the stakeholders of the studied industries, which are explained below.

Commercialization process logic

From the above theoretical contributions, it can be noted that it is highly recommended to use a mixed commercialization logic. Similarly, it can be noted that lean commercialization logic seems to be an appropriate commercialization approach for high technologies, which are full of risks, uncertainties and complexities. Both logics are inculcated in the ICP model, which enables commercialization teams to plan their commercialization properly and to be flexible with their plan. For instance, the model outlines different activities to be performed at different phases, as Table 8 showed. Additionally, the model proposes a *Server engine* and continuous execution of its activities. These activities provide direction during the commercialization process. The model notes that the commercialization team should ensure that it gains commitment from stakeholders and that it keeps track of *changes*, especially uncontrollable changes. All these features of the ICP model make the process flexible. Therefore, the commercialization process logic is one of the current study's insight for the studied industries.

Commercialization process knowledge

Scientists and engineers are potential entrepreneurs because they innovate and can decide to take their innovation forward. This group of people needs some

knowledge about the commercialization process. As previously argued, a commercialization orientation enables potential entrepreneurs to take the necessary steps during their pre-innovation, innovation and post-innovation activities. Fortunately, the current study offers commercialization knowledge for them. For examples, the current study outlines some challenges that potential entrepreneurs can consider at the initial stage of their decision to commercialize. Consideration of those problems would help them to know what they must do. Similarly, potential entrepreneurs must consider their technology's enabling factors, such as the interest, focus or need of a target market; the technical possibility of the technology; any current IP issues for the technology; the availability of infrastructure and upcoming policies. These factors, which would enable them to be prepared, flexible and agile, are outlined in this study. Additionally, the potential entrepreneurs can sketch their commercialization plan according to the ICP model. This would assist them to have a broad view of their commercialization process as well as to coordinate the process effectively and efficiently. The model is developed by the current study.

Apart from the potential entrepreneurs, experienced entrepreneurs can improve their commercialization competence. For example, experienced entrepreneurs are usually conscious of risks and uncertainties. With the ICP model, they can plan their new commercialization process or review their existing processes. They can also understand the current stage of their commercialization plans. Most importantly, the server engine of the ICP model would keep them focused, flexible, agile and responsive. The elements of the server engine would enable them to be cost effective and efficient.

The current study also provides commercialization knowledge for intrapreneurs. This group of people often strikes a balance between their individual entrepreneurship motive and their organization's constraints. Thus, the ICP model would enable them to be open minded and pragmatic. It would enable them to be vocal when presenting or discussing their commercialization interest with their superiors. For example, it is logical to show problems, factors, process and benefits of commercialization projects, which can be drawn from ICP model. Presenting a commercialization project that shows the possible activities to be performed at various phases, how to manage unexpected circumstances and possible project outcomes would be more convincing than a presentation without a broad view.

Furthermore, this study provides commercialization knowledge for companies, especially from the selected industries. Nowadays, a company's size does not necessarily limit its capacity to put its high technology forward. Thus, the ICP model would enable companies to acquire knowledge for their commercialization process. It would enable them to pay attention to the elements of a server engine, which might be neglected in some cases. The ICP model would enable them to have a comprehensive view of their commercialization activities. It also enables

them to be responsive to changes that can affect a business either expectedly or unexpectedly. It enables them to provide the necessary support to their commercialization team. Similarly, research institutes can benefit from the current study's commercialization knowledge. According to Etzkowitz et al. (2008), Foss & Gibson (2015) and Guerrero et al. (2016), a university that is a key part of research institutes embraces a third mission, which is to be entrepreneurial. Similarly, Still (2017) and Gbadegeshin (2017a) stated that research centers are presently pursuing entrepreneurship. These institutes purposely pursue entrepreneurship through commercialization of their inventions and innovations to generate income. The ICP model would enable them to improve their commercialization projects. It would also enable them to have an overview of their commercialization activities and to support their commercialization teams.

Last, the current study provides commercialization knowledge for entrepreneurship educators. With the entrepreneurship mission of the research institutes, there are efforts to improve how entrepreneurship can be trained. According to Heinonen et al (2007), flexible teaching methods and contents, and using of business simulation with timing seem to be success factors for providing entrepreneurship training for specialized field like Life Sciences and ICT. Hence, ICP model provides tools for these success factors. For instance, business simulation can be developed with ICP model and different commercialization activities could be used to in developing program contexts. Therefore, the current study provides practical contributions.

5.5 Limitations of the Study and Suggestions for Future Studies

According to Yin (2003) and Creswell (2009), each research method and instrument has its advantages and disadvantages. The merits and demerits of the method pose limitations to the research. The scholars also note that both challenges and limitations often enable researchers to continue their studies. Thus, this section presents the limitations and suggestions for future studies.

The focus of the current study provides a better understanding of the commercialization process. The study focuses on high technologies, which are different from the low or matured technologies, and it also focuses on three industries. The characteristics of these industries seem to be common among the high technology–based industries, according to De Bruijn (2006) and Solberg et al. (2008). However, this focus poses a limitation in that the number of industries and their participating companies serves as a limit.

The current study used a variety of cases and case study technologies. In article 1, QKD was the focus, while measurement technology was the focus in article 2. Article 3 focused on many high technologies from the selected industries,

but article 4 focused on the high technologies from the Life Sciences. Similarly, there is a variation in the types of companies. Established firms were used in articles 1, 3 and 4, but they also concentrated on a new Spinoff. Although these variations added value to the current study by providing more insight into commercialization, their variations pose limitations.

Additionally, the current study observed the technologies of the commercializing companies located in Finland. These technologies are marketed internationally, and their company has branches or distributors across continents. Similarly, the features of Finland make it a good representative of advanced countries, and its position on the global stage makes the country a leading global nation, according to WIPO (2017) and the World Economic Forum (2017). However, focusing on companies situated in a highly developed country poses limitations to the current study in that these companies have access to a favorable business environment that similar companies in developing or emerging economies might not have. Therefore, this focus could be a limitation to the current study.

Furthermore, there are methodological limitations, one being the use of public information. For instance, articles 2 and 3 used secondary data, which were collected from official organization and news sources. Normally, this kind of information is expected to be credible. Meanwhile, there might be some issues *just to satisfy a formality* or *to be politically correct* These limit the quality of the data. Additionally, information collected from the companies' websites might have a *marketing* undertone, which suggests the use of secondary data, which can limit the quality of the data. Another methodological limitation is the number of participants. Although the current study has many participants who represent all stakeholders of the commercialization process, the number of survey responses is a limitation to the study. The survey instrument was used in article 1. Sixty people participated, representing stakeholders of QKD technology in the European Union (EU), but this is a limitation considering the number of respondents in relation to the whole EU. Another limitation is the use of first-hand information in this study, which was achieved by agreeing to maintain confidentiality. For all interviews and observations, the researcher signed a Non-Disclosure Agreement (NDA). The NDA was a constraint in paper 2, in which the study's researcher was a team member. Without this constraint, the current study might have produced more insights. Therefore, confidentiality seems to be a limitation to the current study. All these methodological limitations were addressed by the validity and reliability strategies (discussed in section 3.4).

Finally, these limitations call for further studies on the current topic. First, the current study employed different theories, theoretical frameworks and models. These theoretical backgrounds are important for the commercialization process, and they are related. Meanwhile, it is hoped that further investigation of the commercialization process with a specific theory might provide more knowledge

by employing especially from the entrepreneurship field. As explained earlier, creative entrepreneurship process theories are very much related to the commercialization process, though the scholars have not yet been investigated the theories in relation to the process. Thus, it would be interesting to see an intensive study on the commercialization of high technologies employing the Effectuation and Bricolage entrepreneurship theories. It is hoped that the application of such theories would shed more light on the process. Some scholars, including McCoy et al. (2008), Rasmussen (2011) and Lavoie et al. (2017), had called for the application of entrepreneurship theories on commercialization. Therefore, synthesizing the process with entrepreneurship theories would complement the current study's findings.

Second, the current study focused on three industries. These industries are relevant to the study of commercialization process. Similarly, the current study centered on the high technologies and it used companies in Finland. Meanwhile, it would be more interesting to find out whether other industries might provide new and different insights on the high technology commercialization process. Additionally, it would be interesting if future study could investigate commercialization process of the high and low technologies together purposely to provide a better understanding of both processes. Similarly, it would be good to know if the future study can examine the process with companies outside Finland, especially from developing and emerging economy nations to gain a better understanding of the commercialization processes of high technologies from ICT, Cleantech and the Life Sciences.

Third, the current study identified challenges to the commercialization process, including scattered and small markets, supply chain development, technology validation/certification, lack of available or adequate infrastructure, after-sales services, technical development, customer orientation / awareness, and government regulations. These challenges can be used as variables for quantitative studies to determine if they affect the high technology commercialization process, especially for ICT, Cleantech and Life Sciences companies. Similarly, the current study identified some factors that could facilitate commercialization of high technologies. The factors are university vision and interest; personal interest and motivation of both innovators and business team members; the ability of innovators to identify an opportunity and industrial or legal knowledge; working experience of the commercialization team; trust and previous positive collaboration in the team; individual networks of the team; industrial connections / relationships; good leadership and team commitment, international networks and creation of awareness and industrial collaboration. These factors can also be used as variables for quantitative studies and can be tested to examine their impacts or influence on the commercialization process. Using the above variables for quantitative studies might validate some of the knowledge the current study has pro-

duced. Therefore, it would be good to see quantitative studies examining the variables just listed.

Last, this study proposed the ICP model in ICT, Cleantech and the Life Sciences. The model seems to be useful for an empirical study because it has theoretical assumptions and practical features in the high technology sector. Hence, investigating both the theoretical assumptions and features might test and validate knowledge of the model. Applying the model qualitatively in other industries or sectors may reveal whether the main elements of the model are also present in other contexts. Similarly, the model could be tested quantitatively on the selected industries but with many companies or countries. Applying the model empirically might provide more knowledge and serve as a foundation for an integrative approach of the study, as Kahn et al. (2006) have argued that employing different perspectives would improve the success of the companies' NPD, and some scholars have also demanded that approach. Thus, it would be interesting to see empirical research on the application of the ICP model.

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