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Factors, Routes, and Existing Theories of Technology Commercialization in University: A Conceptual Framework

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ABSTRACT

This research uses systematic literature reviews to explore key influencing factors, routes, and existing theories of technology commercialization in universities. This study found that the technology commercialization mechanism in universities consists of three phases, with licensing and spin-off creation as its channel. Furthermore, the success factors for the commercialization of technology in universities include the academic entrepreneur, the role of technology, the availability of the market, the availability of finance, intermediaries' support, the role of the collaborative research centre, policy support, and regional infrastructure and environment. Meanwhile, the existing management theories that discuss the topic mostly use a resource perspective such as Resource-Based View (RBV), resource orchestration theory, and dynamic capabilities with universities and spin-offs as units of analysis. This study provides several recommendations for future studies besides providing a conceptual framework. First, it needs to expand the analysis not limited to licensing and spin-off. Second, it is suggested to develop a resource perspective by enriching what dimensions influence technology commercialization success or providing alternative new management theories. Third, using developing countries as context, we can potentially generate new concepts of technology commercialization, both from the route and key success factors.

I. INTRODUCTION

Universities extended their mission from teaching and research activities to entrepreneurial activities that support economic growth and social empowerment (Etzkowitz, 2004). This new mission enables the universities to support technology commercialization activities actively (Rasmussen et al., 2006) by bringing innovative ideas and inventions to market (Bradley et al., 2013) to contribute to regional economic growth and even countries and social welfare (Schmitz et al., 2017).

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By definition, technology commercialization transfers technology-based innovations from technology developers to organizations that use and apply these technologies to marketable products (Kirchberger & Pohl, 2016). Etzkowitz & Zhou (2021) refer to the commercialization of technology as the transmogrification of inventions into economic activities. Technology commercialization activities are intended to create value of both social and economical from the university's knowledge and ensure that this value is implemented and practised (Dalmarco et al., 2018).

Technology commercialization, as stated by (Kochenkova et al., 2016), is an essential means for universities to maintain their position in creating new mechanisms to fund their research exploitation activities, such as royalties on licensed technologies, revenues earned from shares in academic spin-offs, research contracts, consulting services with companies. Commercialization can also strengthen the innovation ecosystem by supporting startups or emerging knowledge-based firms, supporting the creation of academic entrepreneurship, and becoming a source of university income (Bradley et al., 2013).

Commercialization is a critical stage of technological innovation (Chiesa & Frattini, 2011; Shah & Pahnke, 2014), and the success of this process is tiny. Parker & Mainelli (2001) revealed that out of 100 university research ideas, only ten were forwarded to research projects. Of the ten projects, only two have commercial potential; of these, only one is profitable. Furthermore, technology commercialization activities are often interpreted as something in a black box where models are generally difficult to find (Bradley et al., 2013).

The higher education sector, such as universities, is now faced with the problem of financial sustainability (nytimes.com), which can be overcome by adopting the right technology commercialization. A strategic option that can be implemented to solve this problem is to carry out a university diversity revenue stream. One of the channels of which is the commercialization of intellectual property rights such as the exploitation of university's research outputs. It is said that startup establishment as one of the mechanisms is able to fulfill with more than double from $7bn to $15bn by 2025 to the market for third-party providers. The President of Pennsylvania State University said that innovation must be placed as a core priority that can drive economic development by bringing research discoveries to the marketplace.

Historically, technology commercialization in universities has gained momentum since the 1980s American Bayh-Dole. Since then, American universities have had the right to own intellectual property (Wood, 2011). The implication was that patent and licensing activity at universities increased, and many University Technology Transfer Offices (UTTOs) were established at universities across the United States (Colyvas et al., 2002). This new mission was initially adopted by several elite universities in America, like Massachusetts Institute of Technology (MIT), Stanford University, and the University of California, then developed nationally (Bradley et al., 2013) and even internationally in various parts of the world.

Apart from the absence of regulatory support, as is the case in the Bayh Dole Act in the United States, developing countries are faced with several challenges, such as the low level of university-industry collaboration (Kirby & el Hadidi, 2019; Carayannis et al., 2016; Dhewanto & Umam, 2009) and small available R&D budget (Dhewanto & Umam, 2009). That is why the study about technology commercialization in the universities at developing countries is interesting because, amidst the challenges, they can still carry out technology commercialization activities.

Studies related to technology commercialization in universities from the existing literature show that it is more equated with technology transfer with wider channels and uses more specific units of analysis such as spin-offs, licensing, or patenting in determining success factors for technology commercialization in universities. There are no studies that specifically address university analysis units with specific commercialization channels, namely licensing and spin-off. There are also no studies that discuss more complete commercialization success factors

by considering internal and external aspects, as well as technology commercialization strategies either through licensing or spin-offs. Finally, no one has studied what existing theories are used in studying technology commercialization at universities. Previous studies also often use the context of developed countries which is less relevant when applied to developing countries.

To answer the gap, this study proposes the following three research questions. First, what are the key success factors of technology commercialization in universities? Second, how is the licensing and spin-off route carried out in technology commercialization in university? Moreover, third, what are the existing theories of technology commercialization in university? To answer this question, after the introduction of the next chapter in this article, we will discuss literature reviews related to the commercialization of technology in university, the methodology we use, findings, and conclusion and recommendation.

II. ANALYTICAL FRAMEWORK

A. Definition of Technology Commercialization

By definition*, technology commercialization* is transferring technology-based innovations from technology developers to organizations that use and implement these technologies in commercial products (Kirchberger & Pohl, 2016; Carayannis et al., 2016). Technology commercialization can be in the form of technology transfer to an industry where conceptual university-produced technology is transferred to the industry to be developed practically in the form of commercial products (Johnson, 2011). This transfer process aims to achieve the university's ambition of creating social and economic value from the technology produced by the university so that it can be utilized (Dalmarco et al., 2018).

Commercialization is a critical stage of the technological innovation process because it is risky and high cost (Chiesa & Frattini, 2011). At the commercialization stage which is a stage of innovation, product identification is carried out, followed by design and development, production and ends with product marketing to the target market (Roberts, 2007). The process is expensive and measuring this commercialization's success takes work. How to evaluate this innovation in the early stages of product development specifically is a question that academics, managers and policymakers constantly ask (Dziallas & Blind, 2019). So determining which model is suitable for commercializing this technology is the work of researchers in innovation.

Technology transfer in universities can can be patent licensing, spin-off promotions, and collaborative research and development (R&D) projects (Dias & Porto, 2018). However, the technology commercialization in university is limited to patent, licensing, and new company establishment activities or spin-offs (Sengupta & Ray, 2017). Establishing new companies and licenses are the two main channels for commercializing university research outputs (Holgersson & Aaboen, 2019). Therefore, the research output in technology commercialization is a product, not a service.

Adopting Ulrich (2012), we can categorize the commercialization of technology in higher education into three phases:

- Basic research. Fundamental research carried out over a long period is sometimes applied to the market. Lecturers and students in the laboratory carry out this activity.
- Technology development. The process of assessing the feasibility of research results for commercialization. Here, concept of Technology Readiness Level (TRL) is used. This activity is carried out by University Technology Transfer Office (UTTO) with patents or other intellectual property as output.
- Product development. Prototypes that have commercial value are then adopted by the industry for commercialization, either through spin-offs or licensing. The university facilitates the process of developing an initial spin-off or the establishment of a new company through a university incubator.

Technology commercialization will become potential as a source of university income, creating research links with industry, and increasing

regional economic growth (Bradley et al., 2013). The university staff and students can get benefits from opportunity in doing research, source in research funding, and access to industry and expertise (www.innovation.pitt.edu). Spin-offs of American academic institution between 1980-1999 contributes to 280.000 jobs in US economy (AUTM), encourage not only regional but also national economic development (Hayter, 2015). Between 1996 and 2013, the economic impact of universities and non-profit patent licensing processes amounted to $518 billion of the United States' Gross Domestic Product (GDP) and $1.1 trillion of the country's GIO (Gross Industrial Output).

B. Technology Commercialization in University

Channel of technology commercialization in university can be categorized into licensing and spin-off creation (Sengupta & Ray, 2017) that can generate revenue for university. License is a right granted by the patent owner that permits other parties to utilize the intellectual property under a written license agreement. Meanwhile, licensing involves technology owners receiving license fees in exchange for technology access and is part of strategic alliances (Trott, 2016). This strategic alliances provide access to more significant resources than any other company can afford. It could be ability to invent new products, to introduce new technologies, to penetrate other markets and to achieve the market scale to survive in market.

In universities, the Technology Transfer Office (TTO) will select licensors that have ability to commercialize the technology through establishing a company or startup. The licensing process is driven by the industry's need for university-developed technology. Previously, this technology was patented on behalf of the University Technology Transfer Office (UTTO); only then did the industry pay for the license by purchasing the university's ownership rights to this technology. Technology licensing agreements facilitate the commercialization by transferring innovation knowledge to outsiders with a fixed fee or royalty (Wood, 2011).

The second channel is creation of a spin-off. New company establishments or spin-offs are entirely new businesses within a university's innovation environment. The company can be owned by the university or co-owned with its partners (Shane & Stuart, 2002). This academic spin-off can be in the form of licensing ownership or using of intellectual property from universities, investment ownership (equity) from universities, and direct establishment by the university (Lockett & Wright, 2005; Wright et al, 2006). The formation of the company can also be determined based on university patents (Rasmussen et al., 2006).

The founders of spin-off company are likely to be the inventors of new technologies themselves (O'Shea et al., 2008), like university students or professors (Rasmussen et al., 2006). This is due to the involvement of these critical researchers in developing spin-offs (de Coster & Butler, 2005). Establishing this spin-off includes a series of processes, from filing patents to licensing and incubating. These spin-offs were established by university patents or even based on tacit knowledge transfer. There are spin-offs that the university incubates, but there are also those that grow outside without direct intervention from the university.

In contrast to developed countries, commercialization in developing countries has its own challenges. In Egypt, the low level of university-industry collaboration drives the need to boost technology transfer and commercialization (Kirby & el Hadidi, 2019). The same problem is also experienced by Russia where to improve collaboration with industry, it is necessary to develop a new administrative standard and also research and business activities that promote innovation and entrepreneurship (Carayannis et al., 2016).

Meanwhile, Indonesia face a challenge where the industry still relies on foreign direct investment and technology (Dhewanto & Umam, 2009). Most foreign companies here only develop their manufacturing plants or setup their distribution offices by positioning Indonesia only as a market. Only a few of the companies establish a research and development (R&D) center. At the same time, a few Indonesian entrepreneurs are

interested to establish a technology-based company. Other challenges faced in Indonesia are the small available R&D budget and the unsuccessful collaboration between universities and industry (Dhewanto & Umam, 2009).

More specifically,Nerkar & Shane (2003) revealed that the obstacle in technology commercialization is the lack of understanding in technology commercialization process and in how to assess the commercialization potential of technology. Another challenges are the lack of resources in building university-industry links (Alibekova et al., 2019) and poor support from the Government and the university management (Nsanzumuhire et al., 2021).

Hertzfeld et al. (2006) added that other challenges from an industry point of view are inexperiencing of TTO staff, lacking of general business knowledge, and unability in increasing commercial potential from university's patents. Long university procedures in negotiating with industry, absence of R&D funding, low market potential for patents (Daniel & Alves, 2020) and institutional bureaucracy (Quiñones et al., 2019).

III. METHODOLOGY

A. Literature Resources

This research was conducted with a systematic literature review (SLR). The term systematics in this research refers to the steps in carrying out research protocols that can encourage evidence-based practice and are the basis for scientific activities, including social sciences (Pahlevan-Sharif et al., 2019). SLR begins by asking research questions, then searching the literature from the database, criticizing the articles obtained, and then creating a logical structure from the selected articles. Using this method, we can get a valuable overview of a certain topic, look for evidence to guide our decisions and can have a real-world impact (Templier & Paré, 2015 in Xiao & Watson, 2019). The database used is sourced from Scopus. This database consists of more than 84 million records with more than 18 million journal papers and 35 percent of the total publications are in social science domain which includes business and management (elsevier.com).

B. Keyword String and Literature Selection

The process of searching for articles in the database requires stages. The first is to determine the right keywords. The first stage begins with conducting a search on the Scopus database with certain keywords that lead to the topic of technology commercialization at universities. The terms "technology transfer" and "technology commercialization" are often used interchangeably because containing same meaning. So, these two keywords are used in the process of this literature study. To limit the university's unit of analysis, each of these keywords is followed by the keyword "university".

Searching from the keywords above, we got 5882 articles. We then criticize the articles. By following the PRISMA flow diagram, we will then conduct screening by limiting Scopus journals which are limited to final articles published in scientific journals, written in English and published in the range 2001 to 2023. We got 2690 articles. Then we screen again by limiting to only articles published in Q1, Q2, and Q3 journals, double article and abstract screening, and 291 articles. We use these criteria to ensure that the chosen articles have great significance on the research topic. Then we entered the eligibility stage by reading full articles, and finally, we got 108 articles that will be included in the analysis.

Table 1. Keyword query string

No	Keyword	Scopus Advanced Search Query String
1	"technology commercialization" and "university"	TITLE-ABS-KEY (*"technology commercialization"* **AND** *"university"*) **AND (LIMIT-TO (PUBSTAGE ,** *"final"* **)) AND (LIMIT-TO (DOCTYPE ,** *"ar"* **)) AND (LIMIT-TO (LANGUAGE ,** *"English"* **)) AND (LIMIT-TO (SRCTYPE ,** *"j"* **))**
2	"technology transfer" and "university"	TITLE-ABS-KEY (*"technology transfer"* **AND** *"university"*) **AND (LIMIT-TO (PUBSTAGE ,** *"final"* **)) AND (LIMIT-TO (DOCTYPE ,** *"ar"* **)) AND (LIMIT-TO (LANGUAGE ,** *"English"* **)) AND (LIMIT-TO (SRCTYPE ,** *"j"* **))**

C. Data Collection and Analysis

The 2690 articles of the searching process in the Scopus database are then stored and downloaded in a comma-delimited (.csv) format. Later on, we fetch it to VoSViewer (Visualization of Similarities Viewer) software with keyword occurrence mapping. This mapping is to see a portrait of previous research related to technology commercialization in universities covering what topics have been researched and what theories have been used in previous research. From this mapping it can be found potential gaps filled by this research. The results of this mapping can be seen in **Figure 2.** VoSViewer is used to see trends that are in accordance with this research topic as well as concepts and existing theories, which become one of the sources in finding gaps in this research. Meanwhile, the 108 selected final articles will be used in the analysis to answer this research question. We use content analysis to analyze the article. This method is a data analysis technique from text using a systematic approach which includes sampling, coding, and quantification (Elango & Kumaravel, 2022).

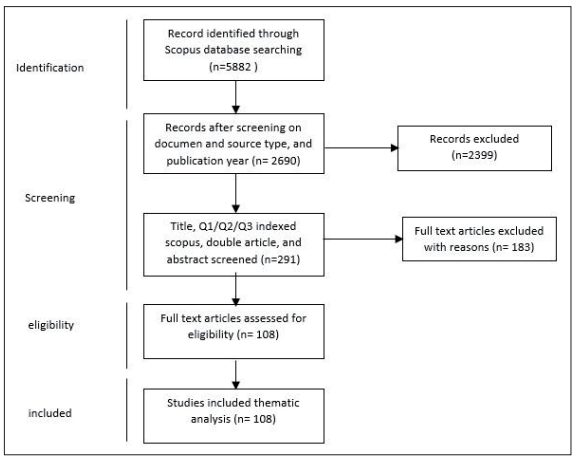

Figure 1. PRISMA Flow Diagram

IV. RESULTS

The findings from VoSViewer provide a portrait of the latest research related to the commercialization of technology in universities in general. We get this analysis from looking at co-occurrence maps (focusing on author keywords) network visualization and density visualization. From the analysis, we get four important findings. First, there are 7 clusters where "technology commercialization" and "technology transfer" occupy different clusters. Meanwhile, technology commercialization is in a cluster with university spin-offs and new ventures.

Second, "dynamic capabilities" is also a different cluster from "technology commercialization", but has links with the keywords "technology commercialization", "technology transfer", "technology licensing", and "university spin-off". However, research with the keyword "dynamic capabilities" was last published in 2012.

Third, the most recent research related to technology commercialization is related to "technology transfer office", "university-industry collaboration", "higher education", "sustainability", and "new ventures". Fourth, the latest research published in 2018 is one related to technology transfer office (UTTO), which has been discussed in several perspectives from entrepreneurial university, triple helix, and human capital, and higher education.

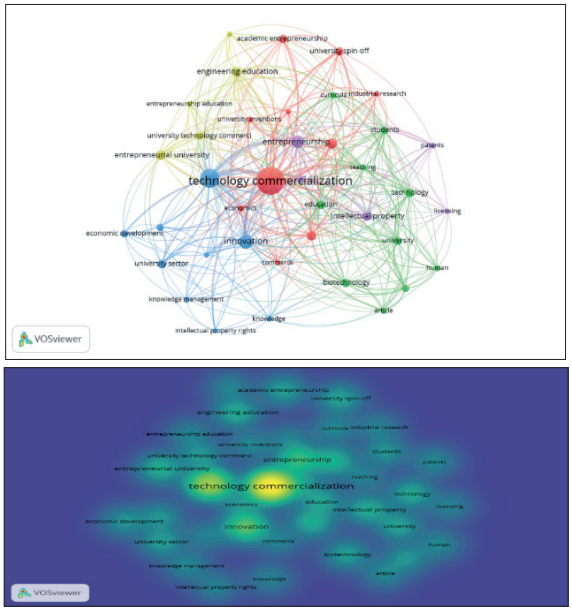

Figure 2. Co-occurrence keywords from Scopus database

Table 2. Commercialization route of technology commercialization in university

Strategy	Explanation
Licensing	• Absorptive capacity of a company, collaboration between private and public, and market competition intensity affects technology commercialization success between university and industry (Min et al., 2019) • There initial stages of technology commercialization process starting lineary from invention disclosure, invention evaluation, definition of IP strategy, filling for IP protection, and commercialization (Jefferson et al., 2017) • The process of technology commercialization begins with scientific discovery, discovery disclosure, invention evaluation for patents, patents, technology marketing, licensing negotiations, and finally licensing by existing companies or startups. This process runs linearly (Siegel et al., 2004).
Spin-off	• University spin-off companies are high-tech ventures that originate from university research work as well as intellectual property that involves the primary role of researchers. Spin-off ownership can be rewarded with an equity stake in the company (De Coster & Butler, 2005). • A spin-off is a company established by a university researcher (faculty, staff, or student) based on the university's research technologies (Hayter et al., 2017). • A university spin-off is a transfer of core technology from a university to a new company whose founding members consist of academic inventors affiliated or not affiliated with the university (O'Shea et al., 2008). • There are four stages in building a spin-off. First, generating business ideas, including academic culture and internal identification of new ideas; second, completing new business projects, including protecting and developing business ideas; third, launching a spin-off company, including access to resources and a spin-off relationship with the home university and fourth, strengthening economic value creation, including the risk of relocation and trajectory changes (Ndonzuau et al., 2002).
Licensing and spin-off	• Technology transfer in university includes formal and informal mechanism with non-linear model (Bradley et al., 2013). • The stage of technological development is the early stage of invention, proof of concept, reduction to practice, and prototyping (Johnson, 2011).

Furthermore, from the 108 selected articles used in the analysis, we conducted content analysis by reading in depth from the articles. Content analysis is a method that helps us give meaning to the data so that the validity and reliability of the findings can be increased (Bengtsson, 2017). We focus on three things, namely the key success factors of technology commercialization in universities, commercialization routes or strategies used by universities, and existing theories that currently discuss the phenomenon of technology commercialization in universities.

A. Commercialization Route

1) Licensing

The stages of commercialization through licensing occur after the technology transfer process (Min et al., 2019). The University Technology Transfer Office (UTTO) then conducts licensing of intellectual property researchers to companies which are then produced by these companies into a marketable product. The UTTO partnership process with companies until the researchers' intellectual property becomes an end-product is a commercialization stage.

Jefferson et al. (2017) mentions the output of research results as invention disclosure which is then carried out through UTTO invention evaluation, definition of IP strategy and filling for IP protection before entering the commercialization stage. In every stage from the invention process to licensing to companies, university scientists are involved in every process (Siegel et al., 2004). While UTTO's involvement has started in the invention disclosure phase and firm/entrepreneur since the licensing phase, namely the process of marketing research results to companies, negotia-

tion, and adoption. The invention disclosure is manifested in the form of a patent.

2) Spin-off

A spin-off is a company established by a university researcher, both by faculty members and students, based on university research output. The formation of spin-offs involves key researchers who become founding members (O'Shea et al., 2008) and universities that protect intellectual property, manifested in an equity stake in the company (De Coster & Butler, 2005). Besides university inventors, founding members may be unaffiliated with universities (O'Shea et al., 2008).

Forming a university spin-off consists of four stages: generating a business idea, finalizing a new venture project, launching the company, and strengthening the economic value (Ndonzuau et al., 2002). In the second stage, the ideas obtained are protected, and business ideas are developed, which includes technology development, commercial development, and financing. Only then, in the third stage, after becoming a spin-off firm, the founding teams can access intangible and tangible resources and strengthen their relationship with the university. The university bridges the intellectual property protection process through UTTO and the third stage through the university's incubator.

2) Conceptual framework

The licensing route and establishment of the spin-off above is depicted in a linear model. This model was criticized by (Bradley et al., 2013) that linearity was seen as a rigorous and oversimplified process, one-size-fits-all approach, and too emphasis on patentability. The linear model fails to explain the informal mechanisms, fails to account for the impact of organizational culture, and fails to represent the university's reward system in a model. Finally, the nonlinear model is the answer to ttechnology commercialization as a complex process.

Adopting Ulrich (2012) concept, the route of technology commercialization in universities can be divided into three stages; basic research, assessment related to commercialization feasibility, and commercialization (see **Figure 3**). Primary research involves academics, both lecturers and students, who work in laboratories to produce research outputs as inventions. This invention is then assessed (assessment) by the UTTO to be used as a patent. Its commercialization value is studied to be licensed to the industry. UTTO also suggests whether these research results or prototypes are more suitable for commercialization through establishing a new company. At the commercialization stage, which is the core, university incubator taking role in fostering spin-offs.

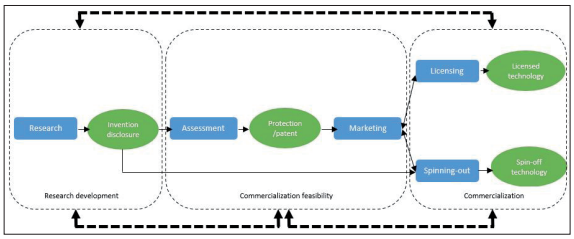

Figure 3. Process of technology commercialization in university

The choice of commercialization strategy between licensing and spin-offs is influenced by the Intellectual Property Rights (IPR) framework, the policy design of the university's technology transfer system, the government's funding system, UTTO's access to business development resources and competencies, and UTTO's monitoring process (Bengtsson, 2017).

In **Figure 3**, the box with the dotted line shows the universities' three phases of technology commercialization. Each phase has a relationship with one other, depicted by a thick dotted line connecting the phase boxes. This link is indicated by a two-way arrow, meaning it is interrelated or feedback and shows a non-linear relationship (Bradley et al., 2013).

C. Factors Influencing University Commercialization

1) Academic entrepreneur

Inventors play major role in technology commercialization process. Inventors who become academic entrepreneurs have unique characteristics that distinguish them from ordinary academics, namely engagement in post-disclosure activity

(Wu et al., 2015), motivation in commercializing their research output (Owen-Smith & Powell, 2001), and their social capital ownership. who are company founders (Shane & Stuart, 2002) or board of directors (Ferretti et al., 2020). Successful academic entrepreneurs are generally those with strong prior relationships with intermediaries (Kim et al., 2019). They are a small number of dedicated and highly motivated persons whose significant impact in succeeding technology commercialization in university (Rasmussen et al., 2006).

2) Role of Technology

Successful commercialization needs to be supported by the characteristics of intellectual property whether it has commercial potential or not. Universities with capabilities in conducting academic and applied research are at the same time a factor of their success in carrying out the process of commercializing technology (Lee & Jung, 2021). Research results which are university's scientist's inventions can enter the stages of protection and commercialization either through licensing or spin-off creation.

***3)** Availability of Market*

Close partnerships between universities and industry becomes impacct of technology commercialization success (O'Shea et al., 2005). In addition to universities that are capable of creating inventions with high commercial potential, prospective adopter companies must also have the absorptive capacity for the university's technology (Min et al., 2019). Capability in this absoptive can be obtained through continuous networking and partnership processes between universities and industry. Through this process, strategic partnership with university can be formed. The implication is that universities can bring new technologies to market (González-Pernía et al., 2013).

The form of networking can be network activities (Kirchberger & Pohl, 2016; Nicolaou & Birley, 2003; Lockett et al., 2003), repeated collaborations (Boehm & Hogan, 2013), joint ventures with other companies (Hayter, 2013), previous inventor intermediary relationships (Kim et al., 2019), and social networks among early-stage academic entrepreneurs (Hayter, 2016).

***4)** Availability of finance*

Industrial involvement, such as venture capitalists, can facilitate the emergence of spin-offs because they can provide necessary financial resources and expertise (Lockett et al., 2003). More broadly, venture capital and angel capital are significant (González-Pernía et al., 2013), especially in the early stages of establishing a new company in realizing an innovation system at the regional level (Wright et al., 2006). Most venture capital investors prefer to invest in university spin-offs after the seed stage when proof of concept has been achieved (Wright et al., 2006).

Links between academia and other parties, such as investors, allow academic entrepreneurs to access a more comprehensive knowledge base that is important for spin-off success (Hayter, 2015). The problem is that academics are often limited by their networks, making it challenging to build relationships with financial industry networks such as venture capitalists (Lockett et al., 2003; Hayter, 2013). In addition to its relationship with the financial industry, the university's geographical location, which is close to the industry, is an essential factor in commercialization success (Jung & Kim, 2018).

***5)** Intermediaries' support*

Intermediary organisations play an important role for universities in increasing their patent application (Temel et al., 2021), licensing and also establishment of spin-off. Intermediary organizations consits of University Technology Transfer Office (UTTO), the university's incubator, and proof of concept center.

University Technology Transfer Office (UTTO)

UTTO assists the patent process among academics, increasing the number of patents and efficiently producing new patents (Rothaermel et al., 2007; Temel et al, 2021). This office disseminates technology to the industry through various mechanisms such as spin-offs, research

collaborations, consulting, technology licensing, education, training of company staff, and exchange of research staff between companies and research institutions (Hsu et al., 2015). The prominent role of UTTO is to link the findings of academicians with companies wishing to use them and facilitate the transfer of commercial knowledge from universities to industry (Siegel et al., 2004).

In addition to marketing inventions to prospective licensees and processing patent applications, the UTTO plays a crucial role in evaluating invention disclosure and licensing inventions to interested parties (Fong Boh et al., 2016). UTTO becomes an 'intermediary' between suppliers of innovations (i.e., university scientists) and those who can potentially commercialize them (i.e., firms, entrepreneurs, and venture capitalists). Marketing activities are the most important for inventions in technological areas where existing links between academia and industry are weak (Colyvas et al., 2002). Generally, UTTO serves in IP, research, and spin-off support.

A good TTO includes properly organized and staffed UTTO (Bradley et al., 2013), experienced and capable staffs (Jung & Kim, 2018; González-Pernía et al., 2013; Shane et al., 2015), specifically employees with research-oriented capabilities (Soares & Torkomian, 2021) and business development capabilities (Lockett & Wright, 2005). Another requirement is UTTO with organizational appropriate structure (Bercovitz et al., 2001). Specifically office with a clear strategy, good relationship with investor, strong networking with industry, and experienced UTTO staff (Zmuidzinaite et al., 2021).

Role of University's Incubator

Incubator also plays a role in facilitating technology commercialization and entrepreneurial activities (McAdam et al., 2006). Incubator is catalysts that enable the process of knowledge transfer and commercialization. Incubator provides office space, equipment, mentoring services and other administrative support to help establish new businesses (Wonglimpiyarat, 2016) such as university spin-off. This incubator was created to reduce the failure rate of the establishment of new companies still in the early stages of growth. An incubator can support the birth, survival, and early growth of new companies associated with the university (M'Chirgui et al., 2016). In addition, the incubator acts as a bridge or mediator by providing investors, incubator members, academic institutions, and various support structures. The incubator helps to provide financial, technical, and management assistance. The majority of incubator maintains a connection with business angel network in order to facilitate access to new sources of financing for the incubated (Lopes et al., 2018).

Role of Proof of Concept Center

Another important intermediary is a proof of concept center. The role of this office is to minimize missed opportunities from selection bias with review boards assosiated only with funding technologies they are familiar with (Gulbranson & Audretsch, 2008).

6) Role of Collaborative Research Center

Not only the characteristics of technology that have high commercial potential, the role of collaborative research centers in establishing networks with cross-stakeholders is important in supporting the commercialization of technology. This institution can reduce geographical and social distance (Villani et al., 2016) and help solving the ineffective cooperation between university and industry (Hou et al., 2019).

7) Policy Support

This policy is needed to overcome obstacles of universities in tackling market inefficiencies (Kochenkova et al., 2016). Policy support includes internal university and national policies. Within the scope of the university includes incentives (Horner et al., 2019), universities' royalty sharing policy (Caldera & Debande, 2010), the incubation program (Wonglimpiyarat, 2016), and earmarking funding to support proof-of-concept (POC) programs in order to bring inventions closer to the market by reducing risk for potential investors (Swamidass, 2013)

While the national scope includes legislative/institutional, direct financing, and competence building (Kochenkova et al., 2016), the form can

be patent regulations (Fini et al., 2011) and giving a sizable investment in university R&D (Jung & Kim, 2018). In practice, such as bringing money directly to universities as is implemented in the UK or supporting new ventures of high technology as part of a technological entrepreneurship policy in France (Mustar & Wright, 2010).

8) Regional infrastructure and environment

The region where technology commercialization takes place also plays an essential role in driving an entrepreneurial ecosystem that can favor the knowledge spillover flow toward the marketplace (González-Pernía et al., 2013). Besides access to venture capital, legal aspect, regional knowledge infrastructure, and industry structure, regions impact spin-off activity (O'Shea et al., 2008).

9) Developing countries context

There were 15 out of 108 articles used in the analysis using developing country case studies, namely Brazil (6 papers), Malaysia (2 papers), and one paper each, namely Indonesia, Thailand, the Philippines, Rwanda, Turkey, Iran, and Kazakhstan. These countries have unique barriers to the implementation of technology commercialization in universities. In Brazil, national-scale policies that can minimize bureaucracy and regulation at the university level have not been implemented (Dias & Porto, 2018), the ineffectiveness in initiatives aiming at promoting academic entrepreneurship (Fischer et al., 2019) and patents are one of the less-used technology transfer channels (Póvoa & Rapini, 2010).

In the Philippines, high costs of managing joint research projects in terms of time and money and institutional bureaucracy (Quiñones et al., 2019). In Kazakhstan, lack of resources to build university-industry links, a lack of time due to high teaching loads, poor qualifications of technology transfer managers, and a lack of networking with industry (Alibekova et al., 2019). In Rwanda, the barriers are the need for more public funding for research, the low interest of companies in collaborating with universities, and the lack of networks, with firms and departments not having structure and procedures related to academia-industry interaction (Nsanzumuhire et al., 2021).

Of the eight critical factors mentioned earlier, several factors are studied in the context of developing countries, namely Policy (Dias & Porto, 2018; Wonglimpiyarat, 2016; Payumo et al., 2014), Role of the intermediary organization (Temel et al., 2021; Davari et al., 2018) with specifically mentioning UTTO and technology commercialization strategy (Dias & Porto, 2018), incubator (Dalmarco et al., 2018), the capability of UTTO employee in research and marketing (Soares & Torkomian, 2021), and intellectual property management and intermediary infrastructure (Alibekova et al., 2019).

Next, namely the availability of finance (Khademi et al., 2015; Alibekova et al., 2019; Renault et al., 2016), availability of the market, such as potential licensees (Khademi et al., 2015) with their absorptive capacity in using university's patent (Póvoa & Rapini, 2010), Technology characteristics (Renault et al., 2016), and Academic entrepreneur that is the founding team and their collaborator (Renault et al., 2016) and having social capital (Renault et al., 2016). Some factors that should be considered are the Proof of concept in the intermediary's support, the Role of the collaborative research center, and regional infrastructure and environment.

10) Conceptual Framework

Commercialization performance can be demonstrated by the number of patents, industries that license university technology, and the emergence of new companies from university research that generate university revenue. This performance is influenced by eight critical roles, namely the existence of academic entrepreneur, role of technology, availability of market, availability of finance, intermediaries' support (i.e. University Technology Transfer Office (UTTO), university's incubator, and proof of concept center), role of collaborative research center, policy support, and regional infrastructure and environment.

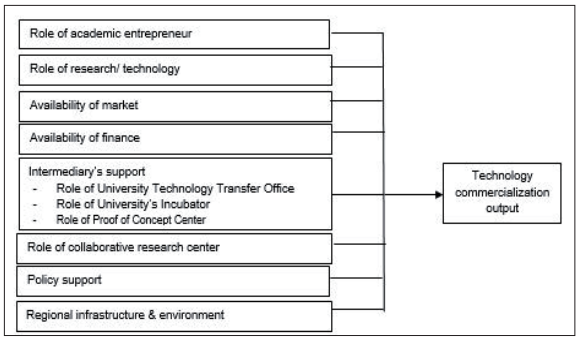

Figure 4. Conceptual framework of managing technology commercialization in university

This model complements (Khademi et al., 2015)'s model, which consists of only four factors, namely the role of the University Technology Transfer Office (UTTO), availability of finance, availability of market (potential licensee), and academic entrepreneur (entrepreneurial orientation). This model is based on eight factors perceived as influential to the university's commercialization which can be called critical success factors (CSF), as stated by (Rockart, 1979).

D. Existing Theories

1) Organization theory

Johnson (2011) and Nelson (2014) use this theory with the university as the context. Johnson (2011) uses organizational control theory (OCT) to analyze the effect of managerial control on performance at each stage of the technology transfer process from university to industry. This analysis also describes how the most effective management varies at each location. Meanwhile, Nelson (2014) explains how the impact of organizational context on academics' decisions to become entrepreneurs. He highlights the critical role of context in shaping an academic's entrepreneurial behavior and examines how context shapes behavior.

2) Institutional theory

Fini et al. (2017) used case studies in Italy, Norway, and the UK to analyze the impact of national and university-level initiatives on the number and performance of spin-offs. Using institutional theory and multi-level analysis, they found that changes in the institutional framework at both the national and university levels were proven to create more spin-offs.

3) Resource Based View

Davari et al. (2018) identified the factors influencing academic entrepreneurship at the University of Tehran using institutional economic theory and Resource Based View (RBV). Meanwhile, Guerrero & Urbano (2012) built an entrepreneurial university model using institutional economic theory and RBV.

Hsu et al. (2015) identified the factors influencing technology transfer performance in Taiwanese universities. They used Fuzzy Delphi methods, interpretive structural modeling (ISM), and network process analytics (ANP) to derive the relative importance of various performance drivers. They concluded that human and institutional or cultural resources are critical to university technology transfer. They recommend several policy implications based on these results.

Meanwhile, using the RBV perspective, O'Shea et al. (2005) try to understand why a university is more successful than others in generating technology-based spin-off companies. They reveal that institutional, financial, commercial, and human resources are essential resource and capability attributes in influencing university spin-off outcomes.

Lockett & Wright (2005) identified the influence of university resources and capabilities in creating spin-off companies. They find that the number of spin-off companies created with or without investment is positively related to protecting intellectual property, business development capabilities of technology transfer offices, and university royalty policies. They refer to resources as inputs in the spin-out process of universities and experiences. Meanwhile, capabilities and routines consist of business development capabilities and routines for incentives and rewards.

Using the RBV as a perspective, McAdam et al. (2006) argue that the business process perspective is constructive in conceptualizing critical resource deployments in university spin-offs, namely business support and social support (entrepreneurship networks). In particular, they seek to link processes and network concepts to define future research agendas.

Table 3. Factors influencing technology commercialization in university

Factors		Explanation
Role of academic entrepreneur		• Social capital of company founder (Shane & Stuart, 2002) • Motivation of faculty in commercializing their research output (Owen-Smith & Powell, 2001) • Scientist's attitutes toward research commercialization and their engagement in post-disclosure activity (Wu et al., 2015) • Role of graduate student in terms reconfiguring the organization for marketable technology development (Hayter et al., 2017) • A prior relationship of inventor to intermediaries which help on licensing (Kim et al., 2019) • Role of early pioneers in creating a conducive culture in the beginning of the university's existence (Berggren, 2011) • Engagement of academic individuals on board of directors (Ferretti et al., 2020) • Role of a few dedicated and highly motivated persons in developing courses, study programs, incentives, advice services, and incubators (Rasmussen et al., 2006)
Role of technology as research output		Academic and applied research capabilities (Lee & Jung, 2021)
Availability of market		Absorptive capacity of companies that adopt university's technology (Min et al., 2019)
Availability of finance		Role of venture capitalists in investing after seed stage of spin-off (Wright et al., 2006)
Intermediaries' support	Role of University Technology Trasfer Office (UTTO)	• Improving cognitive and organizational dimensions (Villani et al., 2016) • Serving as an 'intermediary' between university scientist and firms, entrepreneurs, and venture capitalists (Siegel et al., 2007) • Suitable business models that become catalyst and orchestrator (Baglieri et al., 2018) • A properly organized and staffed TTO (Bradley et al., 2013) • Organizational form and strategies for establishing intellectual property rights and in securing revenues from these rights (Bercovitz et al., 2001) • Marketing activities to tackling weak links between academia and industry (Colyvas et al., 2002) • Capability and experience of TTOs (Jung & Kim, 2018) • Experienced technology licensing officers in industry network (Shane et al., 2015) • Employees with research-oriented capabilities (Soares & Torkomian, 2021) • Putting external resource providers in contact with scientists who committed to commercialization (O'Gorman et al., 2008) • Business development capabilities (Lockett & Wright, 2005) • Experienced and expert staff teams and universities with clearly established rules for creating academic startups and having higher patenting records (González-Pernía et al., 2013) • Role in supporting IP, research and spin-off (Brescia et al., 2016)
	Role of University's Incubator	• Role of networks in accessing information and resources and in providing advice and support (McAdam et al., 2006) • Accumulating resource combinations in performance i.e. human capital and financial resource (M'Chirgui et al., 2018) • Maintaining connections with business angel networks to facilitate access to new sources of financing (Lopes et al., 2018)
	Role of Proof of Concept Center	Minimizing missed opportunities from selection bias with review boards (Gulbranson & Audretsch, 2008)

Role of Collaborative Research Center	• Reducing social and geographical gap (Villani et al., 2016) • Tackling the ineffectiveness of cooperation between university and industry (Hou et al., 2019)
Policy support	• At the university level, bringing public money directly to universities. Meanwhile, at the national level, the development of high technology of new ventures as part of a technological entrepreneurship policy (Mustar & Wright, 2010) • Role of policy related to legislative/institutional, direct financial, and competence building (Kochenkova et al., 2016) • For university level, incentives have a greater impact on the effectiveness of technology transfer (Horner et al., 2019) • Policy on universities' royalty sharing strongly affects licensing income. Also, policy of university in encouraging academic scientists to create more spin-offs (Caldera & Debande, 2010) • The incubation program to support innovation (Wonglimpiyarat, 2016) • Patent regulations (Fini et al., 2011) • There are four policies to support the creation of more university startups. First, assess all the university's discoveries as soon as they reveal the potential to set up a startup with competent UTTO staff. Second, UTTO staff with entrepreneurial/investment backgrounds and extensive networks with the investment and business community. Third, encourage academic engineering and science departments to recruit several faculty researchers interested in startups. Fourth, universities should allocate funds to support proof-of-concept (POC) programs to bring inventions closer to market (Swamidass, 2013) • Intellectual property rights for embryonic inventions (Colyvas et al., 2002) • Sizable investment in university R&D (Jung & Kim, 2018)
Regional infrastructure and environment	• The regional context where the technology transfer takes place can favor the knowledge spillover flow toward the market (González-Pernía et al., 2013) • Access to venture capital, legal assignment of inventions, knowledge infrastructure, and industry structure (O'Shea et al., 2008).

M'Chirgui et al. (2018) used the RBV and institutional approaches in assessing the performance of the technology business incubator program established by the French government. This study predicts why an incubator is more successful than another in supporting the development of new science and technology-based enterprises (NSTBF). Meanwhile, Renault et al. (2016) used RBV and a business model perspective in analyzing the influence of the founder team's previous academic trajectory on the business model and academic spin-off performance.

Meanwhile, Lee & Jung (2021) investigated the impact of academic research capabilities, applied research, and operating TTOs on technology commercialization performance. This study identifies non-observable university capabilities as essential to university technology commercialization. The findings of this study indicate that applied research capabilities enable universities to reconcile the different institutional logics of academic and commercial research. Thus universities must have a certain level of applied research capability to make TTO operations effective. This study uses the perspective of resource and capabilities.

4) Resource Orchestration Theory

Wright et al. (2012) developed a framework for determining how resources and competencies can be selected and managed to generate profits from university spin-off firms. This study emphasizes the importance of selecting and organizing human, social/network, financial and technological

Table 4. Existing theories about managing technology commercialization in university

Author	Unit of analysis	Theories	Focus/concern
Johnson (2011)	University	Organizational control theory	Effect of organization control on performance at stages of technology transfer process.
Nelson (2014)	University	Organizational theory	The impact of organizational context to intial decision to become an entrepreneur and specific ways where individuals intrepret and act upon on enterpreneurial mission.
Davari et al. (2018)	University	Theory of institutional economy and RBV	The factors influencing academic entrepreneurship in University of Tehran.
Hsu et al. (2015)	University	RBV	The critical drivers that affect the performance of university technology transfer in Taiwan.
Yuan et al. (2018)	University	Dynamic capabilities	Examining how universities create and capture value in the university technology transfer process.
O'Shea et al. (2005)	University	RBV	Understanding why some universities are more successful than others in generating spin-off company.
Lockett & Wright (2005)	University	RBV	Assessing the impact of university resources and routines/capabilities to creation of spin-off companies.
Fini et al. (2017)	Spin-off	Intitutional theory	Testing wheather national and university level initiative influence on the number of spin-off created and the performance of these spin-off.
Renault et al. (2016)	Spin-off	RBV and business model perspective	Analyzing the impact of previous academic trajectory of the founding team to the business model and performance of academic spin-offs.
Wright et al. (2012)	Spin-off	Strategic entrepreneurship and resource orchestration theory	Explaining how resources and competencies can be selected and orchestrated to generate returns from academic spin-off.
Nicolaou & Birley (2003)	Spin-off	Social network theory	Explaining the role of closure and structural holes, and examining the interaction between relational and structural embeddedness in the academics' network structure.
McAdam et al. (2006)	University incubator	RBV	Reviewing existing literature related to university incubator business processes and networks. This research also seeks to link the process and network concepts to define research agendas
M'Chirgui et al. (2018)	Incubator	RBV and Institutional approach	Assessing the performance of a technology business incubator in France
Lee & Jung (2021)	TTO	Resource and capability as perspective	Investigating the impacts of capability of academic research, applied research, and TTO operation to technology commercialization performance
Min et al. (2019)	Firm	Dynamic capabilities	Showing that the intensity of market competition is a key factor in moderating the effects of partnership and absorptive capacity on the successful technology commercialization.

resources in seizing opportunities and gaining competitive advantage, achieving growth, and creating value. To develop the framework, they used strategic entrepreneurship and resource orchestration theory.

5) Dynamic capabilities

Using the company as the unit of analysis, Min et al. (2019) show that the intensity of market competition is essential in moderating the influence of partnerships and absorptive capacity on the success of technology commercialization. Meanwhile, Yuan et al. (2018) adopted a dynamic capabilities framework to understand the university's process of creating and capturing value in the university's technology transfer process. Technological exploitation is undertaken to seize opportunities and reconfigure assets to improve suitability for changing environments. Properly managed capabilities enable high operational success.

6) Social Network Theory

The only article that uses this theory is an article written by Nicolaou & Birley (2003). Using university spin-offs as a social network context and perspective, Nicolaou & Birley (2003) adopt a content contingency perspective in understanding the role of structural closures and holes. In addition, they examine the interaction between relational and structural attachments within the structure of academic networks. The results of this study illustrate the importance of networks in the technology transfer process, so academics need to be more actively involved in the technology transfer process.

V. DISCUSSION

The conceptual framework for the commercialization of routes in the universities described in this article is a novelty compared to the models described in other articles, such as (Qian et al., 2018). Qian's model says that the university spin-off process is related to the licensing process, while the model we have developed explains that licensing and spin-off creation may or may not be related. These two things are channels for commercialization in higher education, where spin-off creation can be directly carried out without a product patenting process. Second, Qian's model, which instills sustainable, innovative academic entrepreneurship, is more relevant to the output of a product, while our model is not limited to products but can be a service or know-how as long as it is an invention.

Third, our model is non-linear, where one stage is related to another, while Qian's model is unidirectional and linear. The non-linear model refers to (Bradley et al., 2013), which criticize the linear model as an oversimplified process and a one-size-fits-all approach. The model is described by the feedback relationship between commercialization phases where there is an interrelationship between the research development, commercialization feasibility, and commercialization phases.

Of the 108 articles the authors used in the analysis, 15 used management theory as explained in Kessler (2013). From the theory used, most use a resource perspective such as Resource Based View (RBV), Resource Orchestration Theory, and Dynamic Capabilities. RBV theory is used to demonstrate the critical drivers of technology commercialization performance (Hsu et al., 2015), understand why a spin-off university is more successful than other universities (O'Shea et al., 2005), understand the impact of university routines on university capabilities on creating spin-offs (Lockett & Wright, 2005), and understanding university incubator business processes and networks (McAdam et al., 2006).

Meanwhile, some articles combine the RBV theory with others, such as the RBV and institutional economic theory used in identifying factors influencing academic entrepreneurship (Davari et al., 2018), RBV and business models used in nature to analyze the influence of academic trajectory from founders on business models and spin-off performance (Renault et al., 2016), and RBV and institutional approaches used in assessing the performance of technology business incubator programs (M'Chirgui et al., 2018). Lastly is the perspective of resources and capabilities used in investigating the effect of TTO academic, applied research, and operational research abilities

on technology commercialization performance (Lee & Jung, 2021).

Other resource perspectives are also used. The first is strategic entrepreneurship and resource orchestration theory which is used to understand how resources and competencies can be selected and managed to produce university spin-offs (Wright et al., 2012). Second, the dynamic capabilities perspective shows the intensity of market competition as an essential factor in moderating the effect of partnerships and absorptive capacity on commercialization success (Min et al., 2019). The third is the dynamic capabilities framework used in examining how universities create and capture value in the university's technology transfer process (Yuan et al., 2018). Other theories used are organizational theory (Johnson, 2011; Nelson, 2014), institutional theory (Fini et al., 2017), and social network theory (Nicolaou & Birley, 2003).

Finally, this article can be a reference for researchers who wish to study technology commercialization at universities, using the existing theories mentioned in this study or even using other theories. This study can be a source for universities to determine appropriate technology commercialization governance strategies based on the key influencing factors described in this article. This study took limited data from the Scopus database; further studies need to be expanded to other databases so that later other findings will be produced that complement this study.

VI. CONCLUSION

Technology commercialization in universities can be divided into three phases: basic research, commercialization feasibility, and commercialization. The three phases run non-linearly, where there is a connection from each stage by looking at the active interactions between the actors. In the commercialization phase, two channels can occur in universities: licensing and spin-off creation. As for commercialization success, there are eight influencing factors, namely academic entrepreneur, the role of technology, availability of market, availability of finance, intermediaries' support (i.e., University Technology Transfer Office (UTTO), university's incubator, and proof of concept center), the role of a collaborative research center, policy support, and regional infrastructure and environment.

Meanwhile, the existing management theories that discuss technology commercialization in universities mostly use a resource perspective, such as Resource-Based View (RBV), resource orchestration theory, and dynamic capabilities. A few use other theories, such as organizational, institutional, and social network theories. Most theories use university analysis units, followed by university spin-offs, incubators, UTTO, and firm analysis units.

The findings from this literature study provide several recommendations for future studies. First, this study limits licensing and university spin-offs for university technology commercialization. Therefore, future studies can expand on the possibility of other channels. Additional channels will affect the commercialization route, influencing factors, and the theory used to analyze. Second, future studies that use university, spin-off, incubator, and UTTO analysis units can use theory with a resource perspective, such as RBV and dynamic capabilities. The use of which theory is more suitable according to the initial assumptions on market dynamics, whether static or dynamic. It is also advisable to explore what internal and external resources influence the success of technology commercialization in universities.

Third, commercialization studies at universities in developing countries with unique challenges can be carried out by measuring the relevance of the key success factors resulting from this SLR study. It is also possible to find other key influencing factors through exploratory studies. This will create a new concept related to technology commercialization in universities in developing countries.

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