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The Relationship between Knowledge Structuration and Technology Diversity: A New Solution for an Old Problem

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Abstract

Knowledge, as a constituent of a firm's intellectual capital and the outcome as well as a major driving force of its R&D process, is essentially different from technology. However, the literature on knowledge and technology management often treats the two terms as equal, particularly when it comes to empirical measurement. The present research contributes to the literature by providing distinct empirical approaches to knowledge and technology, among other contributions. More precisely, we find a research gap on the link between a firm's structuration of technical knowledge (across dimensions of depth and breadth) on the one hand, and its technology diversity on the other. To address this issue, we offer a novel approach based on the machine learning method to identify a firm's technological capabilities. The applicability of the proposed method is then illustrated by analyzing technological capabilities in 204 biopharmaceutical firms during the period 2006-2018 and comparing these capabilities with the firm's patents. The results show that there is a positive relationship between the breadth of knowledge and technology diversity in a firm, while the relationship between depth of knowledge and technology diversity is negative. Furthermore, the firm product/market diversification strategy moderates the relationship between the breadth of knowledge and technology diversity. The findings also indicate that knowledge and technological capabilities must be analyzed differently. Implications for research and practice are discussed.

Key words: Knowledge Structuration, Technology Diversity, Diversification, Machine Learning Method, Biopharmaceutical industry.

1. Introduction

Early definitions of intellectual capital often equate the term with “knowledge”, e.g. (Stewart, 1997) defines it as “Packaged useful knowledge”, and (Edvinsson and Sullivan, 1996) describe it as “a stock of focused, organized information (knowledge) that the organization can use for some productive purpose”. The definition later evolved to include three main components, namely human capital, organizational (structural) capital, and relational capital (e.g. Andriessen, 2004; Barrena-Martinez et al, 2020; Roos, Pike, & Fernström; 2005; Wall, Kirk, & Martin, 2004). However, it is curious that the ambiguity around the terms “knowledge” and “technology” is still present as the two terms are often used interchangeably, while they are fundamentally different and conceptually distinguishable. Many empirical pieces of research rely on proxies of “technical knowledge” while trying to measure some aspects of “technology”.

In addition to the ambiguity that stems from equal empirical treatment of “knowledge” and “technology” by management scholars, little has been said about the relationship between knowledge structuration (across dimensions of depth and breadth) on the one hand, and technology diversity, on the other. Knowledge is a fundamental constituent of intellectual capital, and technology diversity is often viewed as a consequence of the R&D management process. It is therefore important to bridge the two concepts in response to the recent call for research. The present research contributes to the literature by offering distinct empirical approaches to knowledge and technology, among other contributions.

Early definitions of technology include ‘a set of pieces of knowledge’, (Dosi, 1982, p151), and ‘an area of specialized technical expert knowledge or the practical application of knowledge’ (Granstrand and Sjolander 1990, p. 59). While knowledge (more specifically technical knowledge) is the main constituent of technology, a major distinction is that technology includes tools and skills as well (Khalil, 2000). In fact, application of knowledge in a process in order to produce products or services requires also some specific tools and skills.

Technologies incorporated in processes (i.e. technological capabilities) are the main building block of firm value chain and play a major role in its competitive advantage (Porter, 1985). Despite its importance, academic researchers and practitioners in the area of technology management are faced with a difficult challenge in attempting to measure technological capability at the firm level (Schoenecker and Swanson, 2002).

Technological capability is historically measured by R&D investments as the input indicator and number of patents registered by the firm as the output indicator (see for example, Hall and Bagchi-Sen, 2002; Tsai, 2004; Coombs and Bierly, 2006; Reichert and Zawislak, 2014).

Patent-based measures are widely utilized in the literature. While this conceptualization of technological capability enables an effective operationalization thanks to the international patent system, scholars have pointed out limitations to the use of patents as a proxy for technology (Ceipek et al, 2019). In fact, the patent system would, at its best, offer a measurement of technical knowledge embedded in technology but not the exact entity that technology is. Measuring technological capabilities using patents does not engage with physical devices (Dosi, 1982) as a

part technology, neither does it capture the materiality (Leonardi and Barley, 2010) or actual ‘use’ of hardware (Orlikowski, 2000).

Moreover, technologies embodied in the firm’s processes such as manufacturing, customer relationship management (CRM), supply chain management (SCM) or enterprise resource planning (ERP) are often acquired through external sourcing. In other words, they are not rooted in R&D and do not come necessarily from the patents registered by the firm. This is why technology-based applications and processes have normally been overlooked in the patent-based measuring of technological capability (Hendricks et al, 2007).

Building on the contention that technical knowledge is conceptually distinct from technology, this study uses patent counts for measuring knowledge stock of a company and takes advantage of advancements in Natural Language Processing (NLP) for offering a novel way to enumerate technology (i.e. technological capability) portfolio that is ‘actually used’ by the same company. The present study, therefore seeks to answer the following question:

How does the knowledge structuration¹ of a firm affect its technology portfolio?

In the next section, we will distinguish between two concepts of technology and knowledge. In section 3, the theoretical background is reviewed and some hypotheses are accordingly introduced to navigate the relationship between knowledge structuration and technology diversity. Section 4 is devoted to the research methodology and main variable (dependent, independent and control variables) description. Section 5 discusses the correlational analysis between knowledge structuration and technology diversity and shows how market diversification moderate the impacts of knowledge structuration on technology diversity. In the last section, we will conclude the paper by its theoretical contribution and practical implications and provide recommendations for further studies.

2. Technology Vs. Technical Knowledge

The word “*technology*” comes from the Greek “*technologia*” which is derived from “*techne*” and “*logia*”, two Greek words. It is thus literally a combination of “an art and a technique, involving both a knowledge of the relevant principles and an ability to achieve the appropriate results” (Wheelwright, 1966, p. 328). Cambridge Dictionary defines *technology* as “the application of scientific knowledge for practical purposes”. According to this definition, technical knowledge is a constituent part of technology and not equivalent to the technology as a whole (Herschbach, 1995). Despite this clarification, why does the literature still use knowledge and technology interchangeably? We believe that the main reason is related to the trouble of measuring a firm’s technological capabilities. Technology is embodied in a specific process and therefore is not context-free. In other words, measuring each kind of technological capability requires specific measures as well as measurement techniques. This is because technical knowledge has been used widely as a proxy of technological capability by many scholars (see for example, Kortelainen,

¹ The firm’s knowledge structuration comprises the depth and breadth of knowledge the firm possesses and utilized.

Kutvonen and Lättilä, 2013; Schoenecker and Swanson, 2002; Coombs and Bierly, 2006 The academicians prefer to measure technical knowledge instead of technology, since the former is easily measured by patent counts. However, some of them confirm that this is a common but inevitable mistake (Ceipek *et al*, 2019).

To avoid this inaccuracy, we suggest an innovative way to measure technological capability. The applicability of proposed method has been illustrated by investigation of 204 firms in biopharmaceutical industry.

3. Theoretical Background and Hypotheses

3.1. Knowledge Structuration

Rather than trying to define knowledge, the literature is focused on characteristics of knowledge that have critical implications for management and the firm. One of these characteristics refers to depth and breadth of knowledge in the firm, so-called “knowledge structuration”. It is related to the structure of a firm's knowledge portfolio (George *et al*, 2008). Breadth of knowledge indicates knowledge diversity across the firm; the number of different fields of knowledge a firm possess (quantity). While, depth of knowledge is about the mastery of a firm over a specific field of knowledge (quality) (Farazi *et al*, 2019).

Knowledge could be acquired via internal/indigenous R&D activities or external sourcing. In the case that firms aim to acquire knowledge and technology from outside, prior knowledge may enhance their absorptive capacity. This capacity helps them to assimilate external sources rapidly and properly (Cohen and Levinthal, 1989).

Knowledge can be shared in different product and process resulting in firm superior performance (Granstrand, 1998). The knowledge-based theory of the firm considers thus knowledge as the most strategically significant resource of a firm (Grant, 1996).

The effect of knowledge structuration (across the dimensions of depth and breadth) on the firm performance has been widely investigated by different researchers. Several studies have explored the impact of knowledge structuration on the firm's financial performance (see for example, Giuri *et al*, 2004a; Miller, 2004; Chiu *et al*, 2008). (Kim, Lee & Cho ,2016) argued that this relationship follows an inverted U shape pattern². (Miller, 2006) illustrated a positive relationship between breadth of knowledge structuration³ and the market value of firm.

² Kim and his colleagues use the notion of “technological diversification” instead of a “knowledge diversification/breadth”.

³ Miller prefers using the notion "technological diversity" rather than “knowledge breadth”.

3.2. Technology Portfolio

Firms have to manage a wide number of technologies in order to develop and produce products and services. Thus, most firms could be labelled multi-technology companies, even if they are specialized in just one line of business (Granstrand, 1998).

The profile of firm technologies changes slowly over time as a consequence of the inertia of specialization (Cantwell and Andersen, 1996). In other words, technologies and technological capabilities are heterogeneous and differ among firms, as a consequence of path dependency and specialization (Breschi et al, 2003).

Technology plays a major role in customer satisfaction and consequently in the firm's financial performance and competitive advantage. In fact, it is technology rather than technical knowledge which affects the firm's performance. Knowledge along with skills and tools enables firms to perform value chain processes more efficiently and/or more effectively. It allows firms to improve the features and functionality of their products or services. The more diversified the technology profile, the more available the maneuver to improve firm processes and/or products and subsequently the higher the possibility of customer satisfaction.

3.3. Knowledge Structuration and Technology Diversity Relationship

"Technology diversity" refers to the portfolio of technologies embodied in the firm's processes and determines to what extent the firm is diversified regarding its technological capabilities. As mentioned earlier, knowledge (more specifically technical knowledge) is the main part of technology. Technology diversity is therefore influenced by knowledge structuration.

The firm's knowledge structuration comprises the depth and breadth of knowledge the firm possesses and utilized. Breadth of knowledge indicates knowledge variety across the firm and depth of knowledge refers to the deep understanding of the firm over a specific field of knowledge. Focusing on a narrow set of knowledge over time could result in a knowledge base with much greater depth (Nerkar and Paruchuri, 2005), while acquiring constantly new knowledge would develop a knowledge base with greater breadth (Katila and Ahuja, 2002).

A simple knowledge is not enough for running a value chain. A given set of different knowledge is necessary (Srivastava and Laplume, 2014). In addition, possessing knowledge is not enough. But, it should be combined with other micro-foundations of technology (i.e. tools and skills). In fact, at the core of any value chain, there is technology (and not knowledge) as the building block. Knowledge is only one of three main micro-foundation of technology and need to be integrated with other elements.

Knowledge integration or recombination is one of the fundamental functions of a firm (Grant, 1996). Firms transform existing knowledge into new combinations to create valuable outputs (Fleming and Sorenson, 2001). In addition, the knowledge base is refreshed by bringing in new knowledge components and recombining the new knowledge with existing ones (Katila and Ahuja, 2002).

A knowledge base with greater breadth represents the wide variety of knowledge a firm possesses. All knowledge components are not necessarily exploited in the firm's technology portfolio. But, the more diversified the knowledge profile, the more available the maneuver to exploit them in different technologies and then the more possible the value creation and customer satisfaction (Srivastava and Gnyawali, 2011).

A firm's broad technical knowledge base may also alleviate its exploitation across different products and processes. Furthermore, technical knowledge breadth determines the absorptive capacity a firm requires in order to learn from partners (Zahra and George, 2002; Li and Rowley, 2002). Technical knowledge breadth thus influences the firm's technology diversity. Accordingly, we propose:

Hypothesis 1: A firm's breadth of knowledge is positively related to its technology diversity.

Depth of knowledge represents the degree to which a firm has a deep understanding of a given knowledge domain (George et al., 2008). Greater depth of knowledge base indicates that a firm has a stronger grasp of its technologies (Katila, 2002).

Bases on earlier research, we argue that the deeper the firm's knowledge base, the greater the tendency to use existing knowledge, which is known in the literature as "core rigidity" (Leonard-Barton, 1992) or "competency trap" (Levitt and March, 1988; Srivastava and Gnyawali, 2011). In this case, firms are unwilling and unable to reach out and integrate new knowledge and acquire new technological capabilities. In fact, they try to deploy their current technologies more effectively rather than exploring new knowledge and technologies. Although these firms may potentially be able to benefit from a diverse technology portfolio, competency traps and their strong focus on existing knowledge impede realizing technology diversity. Accordingly, we propose:

Hypothesis 2: A firm's depth of knowledge is negatively related to its technology diversity.

3.4. The Impact of Product/Market Diversification

To fulfill market and customers' expectation, achieve superior and long-term performance and finally gain above average returns, firms should improve their efficiency and effectiveness of processes. Technology plays a major role in this regard, as the enabler of processes (Porter, 1985) and process innovation (Kim et al, 2021).

The firm's technology portfolio evolves in response to the firm's growth and deployment strategies (Yayavaram and Ahuja, 2008). Diversification is a corporate strategy to enter into new products/services or new markets involving substantially different technology and knowledge (Huang and Chen, 2010).

The concept of diversification strategy has been initiated by (Ansoff, 1957) and was subsequently developed by other prominent researchers (e.g. Penrose, 1959; Chandler Jr, 1962 and Peteraf, 1993). They have emphasized that at a certain stage, firms have to diversify their markets to maintain or even increase their growth rate.

Two kinds of diversification have been acknowledged by researchers (Noori et al., 2012), as follows:

1. Resource-based diversification

The firm's decision to become a diversified company is sometimes triggered by internal resources (especially by the firm's technological capabilities). Based on this approach, so-called "inside-out approach" (Dewit and Meyer, 2004), "core capability approach" (Hamel and Prahalad, 1990) or "economies of scope" (Teece, 1980), broader firm's knowledge and technology base provide more capacity for product and market diversification. But, this is a reciprocal relationship, meaning that successful diversification strategy requires some new, often complementary resources (i.e. knowledge and technologies).

2. Market-driven diversification

The firm's decision to become a diversified company could be triggered by opportunities that exist or occur in the market. Based on this approach, so-called "outside-in approach" (Dewit and Meyer, 2004), resources are simply accessible and the main challenge is to identify attractive market/business model to pursue.

In both market-driven and resource-based diversification, to meet the new market requirements, corporations might need to modify and adapt their current products/services or produce new ones. Any change in product/service could necessitate some new or complementary technological capabilities. For this purpose, the firm must take advantage of its accumulated knowledge base and try to build some new recombination of knowledge components (from internal or external sources) and integrate them with other micro-foundations (i.e. tools and skills) in order to create and/or acquire new technologies.

We can thus argue that the strategy of diversification could trigger the recombination of existing and new knowledge components to achieve a new technology portfolio. In other words, product/market diversification could moderate the relationship between knowledge base and technology diversity, as follows:

Hypothesis 3a. The relationship between the firm's knowledge breadth and technology diversity is positively moderated by its market/product diversification.

Hypothesis 3b. The relationship between the firm's knowledge depth and technology diversity is positively moderated by its market/product diversification.

Figure 1 shows all hypotheses discussed above.

Insert figure 1 here.

4. Methods

4.1 Research setting and data

The present paper uses data from different databases. For knowledge structuration we use the USPTO database of firms from 2006 to 2018. For technology diversity of the firms, we use the Clinical Trials website database⁴. We filtered the firms on main Biotechnology SIC Codes of 2834, 2835 and 2836⁵. Based on DISCERN Database⁶ the correlation between patent information of the firms in USPTO Database and market diversification in COMPUSTAT database is well established.

The scope of the present study is Biotechnology firms. Technological change and innovation rate in this industry are rapid and will be useful for measuring technology diversity (Powell *et al*, 1996). Moreover, clinical trials database that used for measuring technology diversity of firms describes different clinical studies of firms that registered according FDAAA 801 rule⁷. We assume, as firms operating clinical trials, they use their technological capabilities. So, with investigating clinical trials, we can find the technologies that firms use.

According to the biotechnology industry, we have found 473 firms with at least one of the 2834, 2835 and 2836 SIC codes in their sales data from 2006 to 2018. 317 firms have sales data in the different SIC codes. ClinicalTrials database contains 341,989 studies⁸ from different firms and research centers from 1999 to 2019. These trials have been correlated to 30,352 unique organizations that conduct clinical trials. USPTO patents database covers all of the companies that we found in the COMPUSTAT database. Finally, we find 204 firms by merging these three databases and considering the firms that report patent information, clinical trials, and sales data for more than three consecutive years in 2006 to 2018.

⁴ <https://clinicaltrials.gov/>

ClinicalTrials is a web-based resource that provides information on publicly and privately supported clinical studies on a wide range of diseases and conditions. This website is maintained by the National Library of Medicine (NLM) at the National Institutes of Health (NIH).

⁵ Two digits SIC code 28 implicate chemicals and allied products. Four digits SIC code 2834 implicates pharmaceutical preparations, 2835 implicates in vitro and in vivo diagnostic substances and 2836 implicates biological products, except diagnostic substances.

⁶ DISCERN (Duke Innovation & Scientific Enterprise Research Network) connects patent information to Compustat firms. for more information please visit "[WHY DO FIRMS INVEST IN RESEARCH?](#)" (Arora, Belenzon and Sheer), NBER WP 23187

⁷ Based on section 801 of the [FDA Amendments Act \(FDAAA\)](#) that is refined in 2016, with the issuance of 42 CFR part 11 for [clinical trials registration and results information submission](#) or as public named "Final-Rule". Based on this statements, firms that operate clinical trials in phase 2-4 interventional studies that are under FDA jurisdiction must register have to register their clinical trials on [ClinicalTrials.gov](#) within 21 days of enrolling the first patient and summary results must be disclosed within a year of the trial's primary completion date.

⁸ The number of trials reported until January 2021.

4.2 Variables

Dependent and independent variables

Knowledge structuration. Knowledge structuration of firms is measured by depth and breadth of patents. Breadth is computed as the natural log of the total number of knowledge areas in which a firm is granted patents. Depth is measured in two steps: First, we calculate the “Revealed Technological Advantage” (RTA) (Soete, 1987) according to equation 1:

$$RTA_{it} = \frac{P_{it} / \sum_t P_{it}}{\sum_i P_{it} / \sum_{it} P_{it}} \quad (eq. 1)$$

Here, P_{it} is the number of patents in firm i and technology class t . Then, depth of the knowledge structuration in firms is calculated as follows (Zhang *et al.*, 2007):

$$depth = \frac{\sigma_{RTA}}{\mu_{RTA}} \quad (eq. 2)$$

Technology Diversity. For measuring technology diversity of the firm, we use “concept embedding” method⁹. In this paper we use clinical concept embedding to map the technological areas to the clinical studies of the firm. As discussed in section 3.1, clinical trials website maintained by the National Library of Medicine. NLM creates UMLS¹⁰ for the concepts and terms that are used in clinical trials studies. Each concept has a specific and unique code, named CUI¹¹. For example, CUI of Leukemia that is known as cancer of the blood cells is C0023418. (De Vine *et al.*, 2014) developed a neural network model for measuring similarity between different UMLS and CUIs. For identifying technology areas in the biotechnology industry, we use OECD biotechnologies classification. This classification contains 32 main technology areas that specify technologies of the biotechnology industry. First, we extract the MESHs¹² of the studies and correlate each MESH to specific CUI. Then, regarding (De Vine *et al.*, 2014) neural model and technology areas of the biotechnology industry, we correlate each study to specific technology areas. We examine each study, determine the technologies that embed with the study, then we collect technology areas of the firm and measure the technology diversity as the number of technology areas of the firm. The approach used for measuring technology diversity of the firms is shown in Figure 2.

⁹ Use Embeddings to Predict Therapeutic Area of Clinical Studies

¹⁰ UMLS (Unique Medical Language System) is a free compendium created in 1986. It provides a mapping structure based on controlled vocabulary in biomedical sciences.

¹¹ CUI (Concept Unique Identifier) is a meaning of concept. A meaning can have many different names. CUI specifies a unique code for different names of one subject.

¹² MESH (Medical subject headings) is a comprehensive, controlled and hierarchically-organized vocabulary used for indexing, describing and classifying the vocabulary. At clinicaltrials.gov each trial has keywords that describe the trial. Two sets of MESH terms assigned to each trial. One is for the condition that trial studied and second one for set of interventions used in trial.

Insert figure 2 here.

Market Diversification. There are several ways to calculate the degree of diversification. Total diversification calculated based on entropy measure for 4 digits sales SIC codes as follows:

$$\text{Total Diversification} = \sum_i^n P_i * \ln \left(\frac{1}{P_i} \right) \text{ (eq. 3)}$$

P_i is the ratio of sales in four digits SIC Code i .

Control Variables

Size. This variable shows the effect of size of the firms and its correlation with capability of the firms to attain technology diversity. Size calculated as the natural log of total sales in different SIC codes.

R&D expenditures. In order to specify the relationship between knowledge structuration and technology diversity, the natural log of R&D expenditures is considered as a control variable. R&D expenditures play a crucial role in acquiring and developing new technologies. (Scott and Pascoe, 1987) stated that technological diversification (or as we called knowledge structuration) is associated with increased R&D expenditures.

Big firms. Big Firms is a dummy control variable that is defined to identify largest biomedical firms based on their sales. If the sale of the firm in a year was more than 10 USD billion, it counted as big firms in the model. We consider this control variable to investigate the capability of big companies in the industry for developing and exploiting the technologies.

Model specifications

We have developed the model based on a fixed-effect estimator in panel data analysis. We consider three years delay between knowledge structuration and financial performance of the firms. We also take R&D expenditures (RDE), size (SIZE) and big firms dummy variable (BF) as control variables, and total diversification (TD), depth (Depth) and breadth (Breadth) of knowledge structuration as independent variables. Table 1 shows descriptive statistics of variables and correlation coefficient between different variables.

Insert table 1 here.

To examine the relationship between knowledge structuration and technology diversity of the firms the eq.4 is used.

$$TECH_{it} = \beta_0 + \beta_1 * Depth_{it-3} + \beta_2 * Breadth_{it-3} + \beta_3 * RDE_{it} + \beta_4 * TD_{it} + \beta_5 * SIZE + \varepsilon \text{ (eq.4)}$$

In the next part, we examine the moderating effect of the market diversification in relationship between knowledge structuration and technology diversity as eq.5.

$$TECH_{it} = \beta_0 + \beta_1 * Depth_{it-3} + \beta_2 * Breadth_{it-3} + \beta_3 * RDE_{it} + \beta_4 * TD_{it} + \beta_5 * SIZE + \beta_6 * TD_{it} * Depth_{it-3} + \beta_7 * TD_{it} * Breadth_{it-3} + \varepsilon \text{ (eq.5)}$$

In this model we consider RDE, SIZE and BF as control variables, TD, DEPTH and BREADTH as independent variables, TD×DEPTH and TD×BREADTH as moderators variables and TECH as dependent variables.

5. Results and discussion

Table 2 shows the results of the correlational analysis between knowledge structuration and technology diversity of the firms between 2006 and 2018. Model 1 indicates the effect of control variables on dependent variable. There is a significant positive relationship between all control variables and technology diversity of the firms. Size coefficient is positive (P-Value <0.0001). Bigger firms are more capable to convert their knowledge into technological capability. Big firms coefficient and R&D expenditure variable are also positive (P-value<0.0001). Model 2 extends the control model by adding the independent variables related to the depth and breadth of knowledge structuration.

Insert table 2 here.

There is a positive relationship between breadth of knowledge structuration and technology diversity of the firms (P-value<0.1). There is a negative and significant relationship between depth of knowledge structuration and technology diversity of the firms (P-value<0.001). The results, thus, support Hypothesis 1 and Hypothesis 2. Hypothesis 1 states breadth of knowledge structuration has a positive correlation with technology diversity of the firms. In other words, firms that seek knowledge in different knowledge areas have more opportunity for developing technological capabilities (P-value<0.1). Hypothesis 2 states depth of knowledge structuration has negative correlation with technology diversity of the firms. In other words, firms seeking deeper in specific knowledge areas are less fortunate to develop and attain technological capabilities (P-value<0.0001). Therefore, both hypotheses are confirmed.

In fact, technology and knowledge are two separate concepts. However, the difficulty of measuring technology diversity has led many scholars to use knowledge measurements for evaluating the technological capabilities of the firms. In contrast, knowledge is easily measured by patent data and is widely validated and used by various researchers. For this reason, in many studies, the technological capabilities of the firms (sometimes called “technological diversification”¹³) have been considered exactly equivalent to knowledge and have been measured with patent data. Patent data can’t explain technological capabilities of the firms. For example, patent registration is not possible or common in many industries, especially in the service industry (Carman and Langeard, 1980). While in these industries, technology plays a crucial role and no value chain can be implemented in any business without technology.

¹³ Technological Diversification, in Strategic Management literature, usually refers to Technology- based Diversification; i.e. product or market diversification which is derived from a firm's technology/technological capability (Noori et al. 2012).

The technology diversity in this research is based on the technological competencies of the firms. One reason for the greater diversity of technology for the firms with broader knowledge structuration is that, the more firms develop their knowledge structuration in a wider area, the more opportunities they face; these opportunities help firms move from R&D and knowledge to technological capabilities and ultimately more technology diversity. Firms with more technological capabilities or more technology diversity are able to meet the needs of different markets.

Finally, the results for the moderating effects reveal how market diversification moderate the impacts of knowledge structuration on technology diversity of the firms as illustrated in Model 3. The coefficient of the interaction between breadth of knowledge structuration and market diversification is statistically significant and positive (P-value<0.05). These results confirm hypothesis 3.a. However, the coefficient of the interaction between depth of knowledge structuration and market diversification is not significant (P-value>0.1) and hypothesis 3.b is not confirmed by the results.

Besides, we consider market diversification as a moderator in the relationship of knowledge structuration and technology diversity. Depending on the needs of the market, the development of different technological capabilities is necessary. Therefore, firms must develop their knowledge structuration to create technological capabilities and respond to market needs. We conclude that firms develop the breadth of knowledge structuration based on needs in different markets, have a better chance for developing their technological capabilities. However, even with strong correlation between depth of knowledge structuration and technology diversity of the firms, market diversification does not play a critical role in moderating effect between depth of knowledge structuration and technology diversity. So, firms with a deep knowledge structuration do not have enough breadth of knowledge to develop their technological capabilities, even when they meet market needs.

6. Conclusion

This paper studied the relationship between knowledge depth and breadth, on one hand, and the firm's technology diversity, on the other. In doing so, we contribute to the literature on intellectual capital by demonstrating a unique and novel approach to measuring technological capability, which is not to be confused with (technical) knowledge. However, this innovative method is only suitable for identifying the technological capabilities of firms performing in the biopharmaceutical industry. It correlates the clinical trial studies of a firm with its technological capabilities, supposing that before launching a clinical study, firms should possess the required technological capabilities. Researchers and practitioners might pursue and benchmark this methodology to propose some appropriate and industry-specific techniques for measuring the firms' technological capability in other industries.

Beyond the aforementioned contribution, we analyzed the relationship of knowledge structuration (depth and breadth) and technology diversity in a firm, which was not investigated earlier, to the best of our knowledge. Our analysis showed that there is a significant positive relationship between the breadth of knowledge and technology diversity in a firm. This means that the more diversified the knowledge profile, the more available the maneuver to exploit them in different technologies which might result in the firm technology diversity. Moreover, the empirical analysis showed that there is a negative significant relationship between the depth of knowledge and the technology diversity in a firm. It means that the deeper the firm's knowledge base, the greater the tendency to use existing knowledge (rather than exploring new knowledge areas) resulting in less technology diversity. This speaks to the literature on "core rigidity" (Leonard-Barton, 1992) and "competency trap" (Levitt & March, 1988; Srivastava and Gnyawali, 2011).

However, the effect of "knowledge" on the firm performance by mediating "technological capability" is still to be explored. The direct effect of knowledge structuration (across the dimensions of depth and breadth) on firm performance has been widely examined. Several studies have explored the impact of knowledge structuration on a firm's financial performance. Notwithstanding, we believe that the impact of knowledge on firm performance could be better explained and interpreted by the mediation of technological capability. Therefore, we suggest that future research should investigate the direct and indirect effects of knowledge structuration on firm performance simultaneously.

In this paper, we also investigated the moderating effect of diversification strategy. The empirical results showed that there is a strong and positive effect of market diversification on the relationship between the breadth of knowledge and technology diversity¹⁴. This finding is fully aligned with previous studies. For example, Miller (2006) indicates that "multi-business firms create more value from technological diversity¹⁵ than do single segment firms, and diversified firms perform better as the technological diversity increases". He has analyzed the moderating effect of market diversification in the relationship between knowledge breadth and firm performance. But, the contribution of a firm's knowledge breadth to financial performance or market value would be

¹⁴ The moderating effect of market diversification in the relationship between depth of knowledge and technology diversity is not significant.

¹⁵ Miller uses the notion "technological diversity" instead of "knowledge breadth".

greater if it derives and expands the firm's technology portfolio since technology diversity via "economies of scope" impacts the firm performance (Zahavi and Lavie,2013).

It is noteworthy that diversification strategy is considered as a general, not specific strategy, while, the literature on strategic management discriminates two kinds of diversification, known as "related" and "unrelated" (Ahuja & Novelli, 2017). The moderating effect of related and unrelated diversification in the relationship between knowledge structuration and technology diversity might be different. It is therefore important for further research to re-examine this effect regarding related and unrelated diversification distinctly.

The most significant managerial implication of this study lies in the fact that technological capability is more essential than knowledge. The firm performance is influenced by how its capabilities (especially technological capabilities) are exploited effectively to support the improvement of the firm's current product and/or processes or the creation of new ones. As mentioned earlier, technical knowledge is a constituent part of technological capability and not equivalent to the technology as a whole. It needs to be integrated with other micro-foundations of technology (hardware and skill). Furthermore, the required technological capabilities could be acquired and learned via external sourcing. It means that some technological capabilities are not routed in internally developed knowledge through the R&D process. Moreover, all knowledge developed in a firm is not necessarily registered or patentable. It is, therefore, necessary to emphasize that top managers should pay more attention to the firm's technological capabilities. Diversified companies could benefit from their knowledge breadth to create technological capabilities if they follow the diversification strategy. Management of technology is concerned with how technological capabilities are developed/acquired and embodied in products and processes to achieve superior performance.

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Tables:

Table 1 - Descriptive statistics

	Variable	Mean	S.D.	1	2	3	4	5	6	7
1	Technology Diversity	5.036	5.152	1						
2	Depth	1.078	0.655	0.057	1					
3	Natural log of Breadth	1.799	0.950	0.177	0.615	1				
4	Natural log of R&D Expenditures	4.256	2.786	0.409	-0.111	-0.129	1			
5	Total diversification	0.144	0.345	-0.116	0.295	0.559	-0.5	1		
6	Big firms	0.114	0.318	0.338	0.355	0.523	0.042	0.182	1	
7	Size	4.981	3.111	0.293	0.429	0.664	-0.036	0.405	0.553	1

N = 1359

Table 2 - Regression results for knowledge structuration and technology diversity relationship

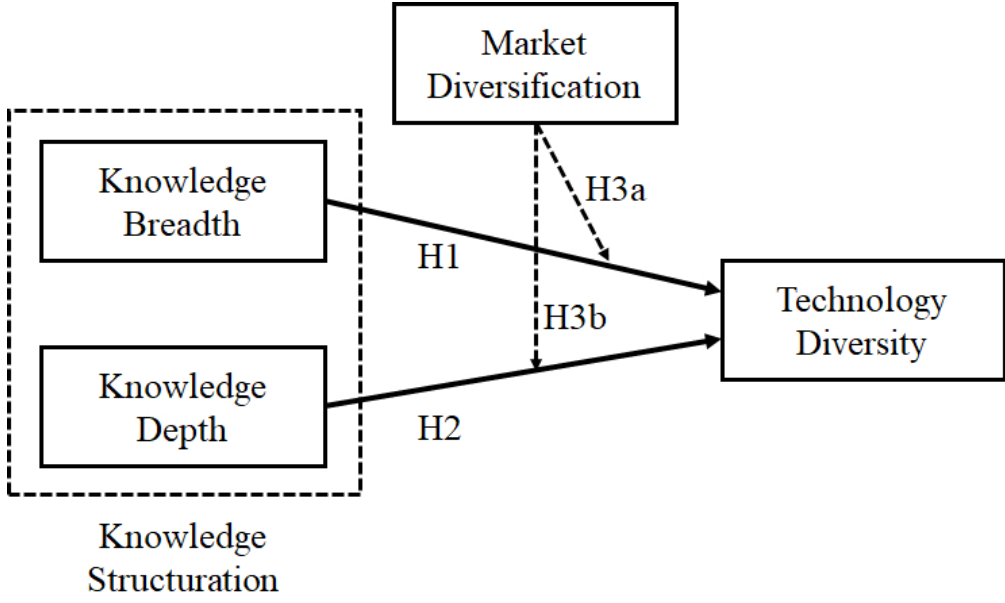
Dependent variable: Technology Diversity			
	Model 1	Model 2	Model3
Intercept	0.019	0.243	0.512
Control Variables			
Natural log of R&D Expenditures	0.709***	0.693***	0.046**
Big Firms	3.503***	3.516 ***	3.799***
Size	0.341***	0.343***	0.351***
Independent Variables			
Natural log of breadth		0.338+	0.112
Depth		-0.691**	0.448+
Total diversification		-0.903+	-1.610
Interactions			
Depth × Total diversification			-1.037
Natural log of breadth × Total diversification			0.682*
Model			
Adjusted R2	0.293	0.3	0.302
Number of observations	1359	1359	1359
Number of firms	204	204	204

p<0.1 +, p<0.05 *, p<0.01**, p<0.001***

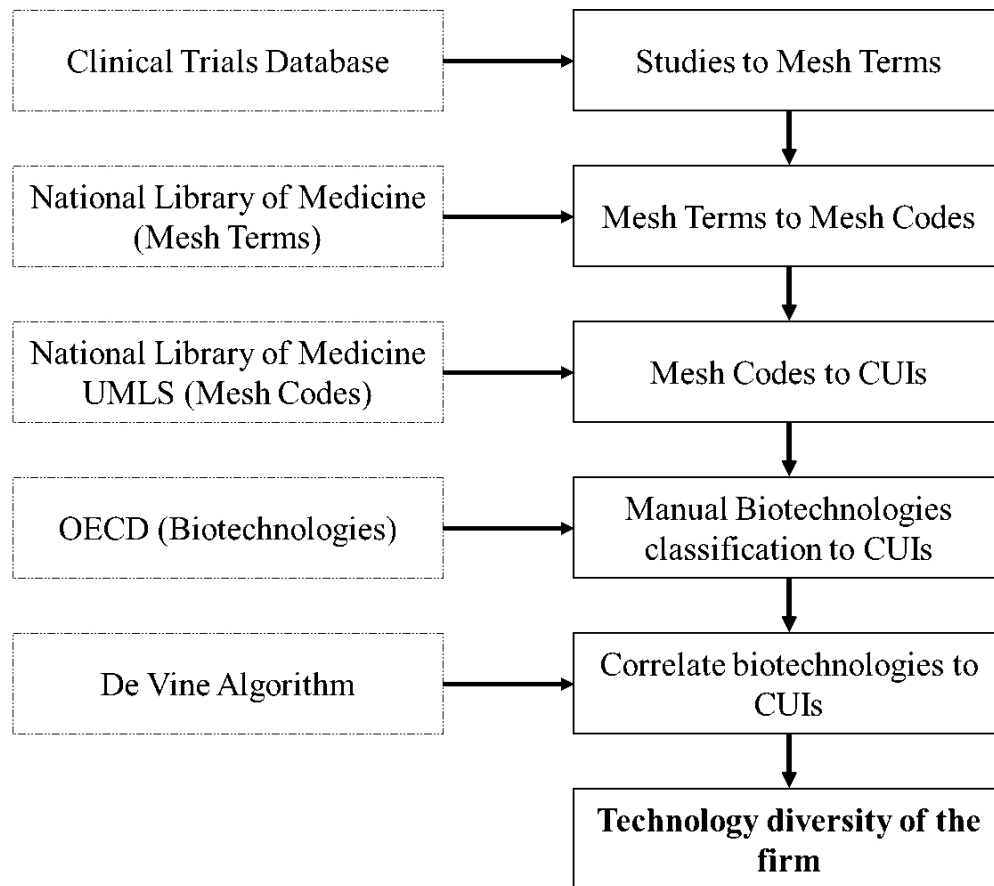
Figure legend:

Figure 1- Theoretical Framework	7
Figure 2- The approach used for measuring technology diversity of the firms	9

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