FUNDAÇÃO GETULIO VARGAS
ESCOLA BRASILEIRA DE ADMINISTRAÇÃO PÚBLICA E DE EMPRESAS MESTRADO EM ADMINISTRAÇÃO

BLOCKCHAIN-SPECIFIC TECHNOLOGICAL CAPABILITY ACCUMULATION: THE CASE OF BLOCKCHAIN INNOVATION PROJECTS IN PETROBRAS

Dissertação apresentada à Escola Brasileira de Administração Pública e de Empresas como requisito para obtenção do título de Mestre em Administração.

HENRIQUE RIBEIRO CASTRO
Rio de Janeiro - 2021

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Resumo

Este trabalho explora diferentes mecanismos internos e externos de aprendizagem, para identificar como as empresas de países emergentes se aproveitam de capacidades existentes não específicas à tecnologia blockchain para desenvolver suas capacidades iniciais, específicas em blockchain, de modo a inovar com esta tecnologia. Estudos sobre o acúmulo de capacidade no nível da empresa ignoraram a blockchain até hoje, enquanto a maioria dos estudos sobre essa tecnologia se concentra principalmente em discussões conceituais ou em especificações técnicas, não se preocupando, entretanto, com as capacidades necessárias para transformar suas invenções em inovações. Mais importante, tais estudos negligenciam as dimensões técnica e organizacional das soluções baseadas em blockchain, o que é decisivo para compreender melhor os diferentes impactos nos processos de acumulação das empresas e nos resultados obtidos. Este estudo é baseado em entrevistas e dados coletados dos dois primeiros projetos de inovação da Petrobras com blockchain, aplicando métodos de análise cruzada dos casos, para examinar como esforços distintos de aprendizagem afetaram a acumulação de capacidades tecnológicas específicas à blockchain. No geral, os resultados indicam que: (i) capacidades não específicas à blockchain tiveram influência na aquisição de conhecimento externo por meio de alianças com fornecedores e universidades, e na criação de conhecimento interno, integrando habilidades multidisciplinares disponíveis na Petrobras, e facilitando a criação de conhecimento por meio de mecanismos internos de pesquisa, experimentação e codificação; (ii) os vínculos de aprendizagem foram fontes importantes de conhecimento externo, atuando como catalisadores da acumulação inicial, mas tiveram que ser complementados por fontes de conhecimento aberto e por mecanismos internos de aprendizagem, quando surgiram lacunas de conhecimento; (iii) foi possível observar o acúmulo de conhecimento no nível da equipe e o funcionamento de mecanismos distintos de aprendizagem entre cada fase do projeto; e (iv) as lacunas de conhecimento eram menos frequentes quando as fontes externas de conhecimento atendiam aos níveis de capacidade exigidos em ambas as dimensões de inovação técnica e organizacional com blockchain. Finalmente, este estudo abre novas oportunidades de pesquisa para estudos sobre acumulação de capacidades tecnológicas específicas à blockchain e também possui implicações práticas, ao traduzir a experiência e fornecer informações detalhadas de projetos reais com blockchain.

Palavras-chave: blockchain, capacidades, acumulação de capacidade, aprendizagem organizacional, tecnologias disruptivas.

Abstract

This thesis explores the combination of existing non-blockchain-specific capabilities with internal and external learning mechanisms, to identify how latecomer firms develop their initial blockchain-specific technological capabilities to undertake innovation activities. Studies on firm-level capability-accumulation had ignored blockchain to this day, whereas most studies on this technology primarily focus on conceptual discussions or on technical specifications, generally not concerned with the necessary capabilities to transform their inventions into innovations. More importantly, such studies neglect technical and organizational dimensions of blockchain implementations, which are decisive to understand the different impacts in firms' accumulation processes and innovation outputs. This study is based on interviews and archival data collected from Petrobras' first two blockchain innovation projects and applied cross-case analysis methods to examine how distinct learning efforts affected blockchain-specific technological capability-accumulation. Overall, findings indicate that (i) non-blockchain-specific capabilities influence on external knowledge acquisition through alliance-making with suppliers and universities, and on internal knowledge creation, by integrating multidisciplinary skills available at Petrobras, which in turn, facilitated knowledge creation though search, experimentation, and codification internal mechanisms; (ii) learning linkages were important sources of external knowledge, acting as catalysts of initial accumulation, but had to be complemented by open-source codified knowledge and internal learning mechanism when knowledge gaps emerged; (iii) it was possible to observe team-level knowledge accumulation and distinct learning mechanisms between each project phases; and (iv) knowledge gaps were less frequent when external knowledge sources met the required capability levels in both technical and organizational blockchain dimensions. Finally, this study opens a research avenue for studies on blockchain-specific technological capability-accumulation, and has practical implications, by translating the experience from real-world blockchain projects.

Keywords: blockchain, capabilities, capability-accumulation, organizational learning, disruptive technologies.

Figures

Tables

CONTENTS

1. INTRODUCTION

Economic growth in developing countries depends largely on firms' innovative technological capabilities. Historically, firms in developed countries benefit from superior first-mover conditions and learning opportunities, which put latecomers in a technological catch-up routine (GERSHENKRON, 1962). To compete in international markets, these firms need to accumulate innovative capabilities by selecting appropriate technology, which best fit indigenous situations (FRANSMAN, 1984). Firms also need to assimilate the new technology, changing their internal processes and developing organizational knowledge to use and improve it (COHEN AND LEVINTHAL, 1990). Connecting with external sources of knowledge is often critical in this process, especially in developing economies, where technological innovation is imported from developed countries (BELL AND PAVITT, 1993). Although taken as weakly articulated (LASTRES, CASSIOLATO, & MACIEL, 2003), knowledge networks in emerging economies are dynamic, especially around key actors (DANTAS AND BELL, 2011; KIM, 1997; LALL, 1987).

Large companies in developing countries play a special role in knowledge network creation, as they use their capabilities to engage in specific learning linkages and develop knowledge networks. Petrobras is one of such companies. Through continuous engagement in learning activities with universities and suppliers for more than 40 years, the Brazilian Oil and Gas company has developed their capabilities to the point of becoming world leader in deep water and ultra-deep-water exploration and production technologies, in an imitation-to-innovation path (DANTAS AND BELL, 2011).

In the context of Information and Communication Technologies (ICT), Petrobras is investing heavily in several technologies in its roadmap to digitalization. For example, the company has recently acquired one of the most powerful supercomputers to support ambitious exploration and production programs. With effect, investments in High Performance Computing (HPC) are significant and it is a showcase to Petrobras contribution to the Brazilian innovative output. From the six supercomputers located in Brazil ranked in the top-500 list of most powerful, Petrobras has three of them, including the only two in the top-100 list (TOP500 ORG, 2021).

Although not as mature as their initiatives in HPC, Petrobras is also experimenting with blockchain technology. Blockchain is one of the most recent information and communication

technologies. It offers disruptive value generation possibilities, being proved useful already, especially cryptocurrencies and digital assets, with Bitcoin becoming a relevant subject and well known to a wider public (BECK et al., 2017). Moreover, most of blockchain technologies are open source, and available in "Blockchain as a Service" (BaaS) architecture, which reduces costs and accelerates technological catch-up for latecomers (similar cases in other technologies are KSHETRI, 2011; ANDERSEN-GOTT, GHINEA AND BYGSTAD, 2012). However, as reported by China Academy of Information and Communication Technology (CAICT), 92% of all blockchain projects failed until 2018 (MALONEY, 2018). Such heterogeneity indicates that some particularities in this technology are significant to project failure and firms need to develop their innovative capabilities to overcome these obstacles.

Swan (2015) divides blockchain evolution in three phases (or 'versions'), the first is Bitcoin and other cryptocurrencies, the second is the use of smart contracts, and the third is the interconnection with other technologies, such as Artificial Intelligence and Internet of Things. From its birth in 2009 to current days, Bitcoin and other cryptocurrencies are already known to the general public, and is increasingly covered by academic research (JIANG, LI AND WANG, 2021). Despite disruptive, cryptocurrencies were not quite adopted by firms in their activities, and Bitcoin did not fulfill the original intent to be a payment system, at least for now it remains a speculative instrument. On the other hand, smart contracts seem more promising to firms given the fact that they can adapt blockchain technology to virtually every purpose (ETHEREUM, 2021).

Although studies proliferate in the literature (FIRDAUS et al., 2019), existing discussions in smart contracts are mostly conceptual (e.g., DAVIDSON, DE FILIPPI AND POTTS, 2018; ROECK ET AL., 2019; AND ALLEN, BERG AND MARKEY-TOWLER, 2019) and empirical evidence is limited to "how-to-use" the technology, use cases propositions or proof-of-concepts (TREIBLMAIER, 2019). Moreover, the bulk of cases report both in academy and in industry are limited to prototypes, with very few exceptions of real-world applications running in 'production' systems (e.g., MENGELKAMP ET AL., 2018; KSHETRI, 2018; KAMATH, 2018). Furthermore, studies regarding the role of capabilities in firms' innovative output with blockchain is, to the best of my knowledge, simply non-existent, which is a considerable gap. The identification of specific knowledge regarding blockchain as well as empirical studies covering how firms are creating their initial capabilities in the real-world provides valuable contribution to academic knowledge and managerial practice, especially with all the noise created by the hype surrounding blockchain technology.

This study explores this research gap by taking the case of two blockchain projects in Petrobras, providing analytical generalization to questions regarding the blockchain-specific capabilities that Petrobras is building, what innovative capability levels the company has achieved with blockchain, and what are the outcomes that Petrobras is obtaining with this technology. To address these research questions, this study adopts a micro-level approach, going beyond the firm as the main observation unit, to investigate the capability accumulation for blockchain-based projects. It adopts a qualitative approach, operationalized through a cross case-study research strategy, and substantiated by fieldwork, interviews, and archival data.

Finally, this study contributes to the theoretical knowledge of latecomer firms' technological capability building in blockchain technology by providing an analytical framework, and by proposing the understanding of the technology by disentangling the technical dimension from the organizational dimension. Empirically, the study provides detailed information over project phases, tracing similarities and discrepancies between them. Moreover, it also contributes to managerial knowledge through showing the importance of choosing between different implementation models, especially the trade-off in capability-building efforts and related costs, and the impacts of identifying and stablishing learning linkages with partners that can provide required knowledge that fits into the technical and organizational dimensions of the chosen blockchain implementation. The remainder of this study is organized as follows: Section 2 is the empirical context and the Petrobras setting, Section 3 is a literature review of existent research in blockchain, Section 4 discusses the theoretical background of innovative capabilities, Section 5 describes the methods, the findings are in Sections 6, with further discussions and conclusions in Section 7.

2. LITERATURE REVIEW

Blockchain is among the most recent technologies related to the industry 4.0, along with Internet of Things, Artificial Intelligence, Digital Twins, Nanotechnology, and others. It has been proven a valuable innovation, in special cryptocurrencies and digital assets, with Bitcoin becoming a relevant subject and well known to a wider public (BECK et al., 2017). However, Blockchain technology is more than Bitcoin, which has a fixed design, as it was conceptualized as a payment system, only allowing users to trade Bitcoins between them (NAKAMOTO, 2008). The technology has evolved since then, allowing programmers to customize their functioning by coding the so-called ‘smart contracts’. This idea was pioneered by the first members in blockchain community (SZABO, 1994) and implemented in Ethereum network in 2015, which opened a wide range of possibilities by enabling developers to create “pieces of code, implementing arbitrary rules or even blockchain-based decentralized autonomous organizations” (ETHEREUM FOUNDATION, 2021).

The bulk of blockchain academic literature is divided in two streams. First, scholars argue over broad possibilities of changes in current institutional arrangements, such as how governance structures could be decentralized (see DAVIDSON, DE FILIPPI AND POTTS, 2018), how digital citizenship can impact regulatory mechanisms (SULLIVAN AND BURGER, 2017), how new economic structures could rise, given an envisioned decentralization of control based on blockchain decentralized applications (ALLEN, BERG AND MARKEY-TOWLER 2019), and impacts in current legal systems (SCHREPEL, 2020; WRIGHT AND DE FILIPPI, 2015). Second, information science (IS) researchers focus on blockchain technicalities, dealing with limitations such as security (LIANG et al. 2017), interoperability (ANGRISH et al., 2018), throughput (SCHUEFFEL, 2017), among others. Moreover, there are many blockchain ‘use cases’ in IS literature, which is how ideas for blockchain-based solutions are called, and also how descriptions of results obtained in prototypes, proof-of-concepts or ‘pilot’ systems. They cover ideas for implementing blockchain in several industries, however very few applications in production level were found in academic literature (Table 1).

Table 1: Blockchain ‘use cases’ per industry and application

Industry	*Brief Description*	*Level of Completion*	*Case Study*
Agriculture	Blockchain in wine supply chain and production for provenance.	Prototype	BISWAS ET AL. (2017)
	Blockchain combined with IoT in agriculture.	Proof-of-Concept	LUCENA ET AL. (2018);

Industry	Brief Description	Level of Completion	Case Study
			CARO ET AL. (2018)
Automotive	Payment System for Electric Cars battery charging services. It is also explored a fully automated process with autonomous drivers and IoT.	Proof-of-Concept	STRUGAR ET AL. (2018)
Aviation	Blockchain use case of a supply chain in aircraft production and maintenance.	Conceptual	MADHWAL AND PANFILOV (2019)
Banking	Information System to provide a KYC platform, that could be decentralized, changing the role of current actors, including regulators.	Conceptual	MOYANO AND ROSS (2017)
Creative	Business strategies to facilitate fund raising via ICOs and venture capital investors.	Production	O'DAIR AND OWEN (2019)
	Blockchain-based platform to secure attribution, transfer, and provenance of digital intellectual property.	Product Development	MCCONAGHY ET AL. (2017)
Energy	Auction mechanism based on a peer-to-peer trading system.	Prototype	LIN ET AL. (2019); HU ET AL. (2019)
	Real-world case study of Brooklyn Microgrid that uses blockchain as a trading platform	Production	MENGELKAMP ET AL. (2018)
Health Care	Clinical data sharing to facilitate effective collaborative treatment and care decisions.	Prototype	ZHANG ET AL. (2018)
	Use case to notarize retrieved data from biomedical database queries, providing immutable audit trails.	Proof-of-Concept	KLEINAKI ET AL. (2018)
Telecommunications	Blockchain integration with IoT for Automatic and on-demand contracting 5G network resources.	Conceptual	VALTANEN, BACKMAN, AND YRJÖLÄ (2019)
Transportation	Blockchain platform to support a network of manufacturers, designers, and costumers, enabling contracting through smart contract execution.	Prototype	HASAN ET AL. (2019)
	Blockchain platform to integrate entrepreneurs and SMEs into transnational maritime supply chains.	Conceptual	PHILIPP, PRAUSE, AND GERLITZ (2019)

Swan (2015) divides blockchain evolution in three phases (or 'versions'), the first is Bitcoin and other cryptocurrencies, the second is the use of smart contracts, and the third is the interconnection with other technologies, such as Artificial Intelligence and Internet of Things. Swan's (2015) three phases in blockchain evolution are not necessarily sequential, they are often being developed in parallel. However, each one is a step further into more complex systems, which imposes more obstacles to adoption and diffusion, demanding more time to mature. Such argument can be confirmed by the fact that, although academic interest (see Figure 1) and practitioners' investments (GARTNER, 2021) are rising, the diffusion of permissioned blockchains are lagging behind Bitcoin, due to different barriers and drivers of diffusion

(HELLIAR et al., 2020). Therefore, while Bitcoin and cryptocurrencies have made their way to increasing adoption, there are still doubts about the future of more advances use cases for blockchain.

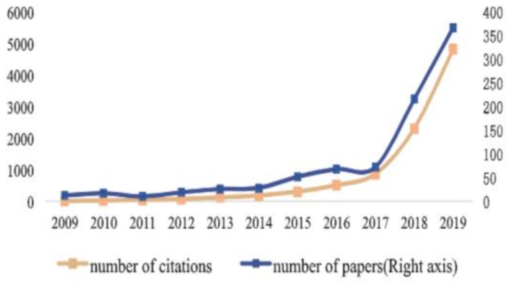

Figure 1: Growth in numbers of citations and publications
Source: Jiang, Li and Wang; 2021

Firms are the main locus of innovative activities, transforming inventions into innovations by combining several different types of knowledge, capabilities, skills, and resources (FAGERBERG, 2005). Bell and Figueiredo (2012) highlight the pivotal role of firm's innovative capabilities in undertaking technological innovation. In fact, firms possess capabilities to produce their products and services, which are important for their daily basis operation, but might not be sufficient for them to undertake technical and organizational changes. Furthermore, developing innovative capabilities is a costly and time-consuming process, resulting from a significantly endogenous accumulation of knowledge over the years. In fact, considerable investments are needed for inventions such as blockchain to become widely diffused innovations, mainly because the advanced knowledge required to develop their features, the increasing technological sophistication and the computational power required to operate it at large scale. Not coincidentally, many large companies, considerable players in their industries, have been forming consortia to fund blockchain initiatives (IBM, 2021). They have been quite active in funding, promoting, and serving as cases for blockchain prototypes. More recently, they have designed blockchain frameworks to attend to their specific needs (e.g., Hyperledger and Corda), which present different configurations from the first public networks (e.g., Bitcoin and Ethereum), such as security, access restrictions, and immutability, for example.

Although not abundant (even in developed countries), there are some studies focused on blockchain implementations in firms. Even so, there are still many studies which based their findings in secondary data, created in the industry (e.g., KSHETRI, 2018; KAMATH, 2018), whether by specialized websites (e.g., Coinbase, CoinDesk), by announcements and business

cases published by companies (e.g., Walmart, Maersk), or by public blockchain communities, consortia, and technology providers. The main issue in relying on such data is that many of them are concerned about creating demand for this technology (also known as ‘hype’), resulting in a lot of noise, which is difficult to filter without close observation.

Among researchers who have the access to primary data, Mengelkamp et al. (2018) show a real-world (i.e., an implemented innovation, with economic impact, not only a ‘use case’) blockchain application for a microgrid energy market. They narrate the state of the technology applied in Brooklyn Microgrid, which is a combination of a physical grid of electric energy created by householders through solar panels, and a virtual grid, which receives data from electric meters and enables neighbors to trade energy in a market platform. Moreover, their study presents the result of years of research and development of solutions to problems in the microgrid setup, from the information system (which include blockchain) to development of the market and pricing mechanisms, and considerations over regulation and legal restrictions faced by the business. Holotiuk and Moormann (2018) reported organizational changes in firms in order to intensify knowledge accumulation and dissemination, such as the creation of internal communities of practice. Beck and Müller-Bloch (2017) show that blockchain implementation projects might be undertaken by the same methods as other information system technologies, which suggests that existing organization capabilities might be exploited, at least to some extent. Specifically in Petrobras’ case, there is one study of an experiment with blockchain. Paskin et al. (2020) show the ‘use case’ of a blockchain-based application for digital signature, describing its features, technical issues, and adaptations to overcome restrictions imposed by their design choices. Although enriching, the studies above are not focused in analyzing how firms developed their capabilities to use or innovate with blockchain.

Very recently, Galati et al. (2021) used Absorptive Capacity and Dynamic Capabilities theories to understand the main enablers for blockchain adoption in Italian firms in winery industry. Their results show that those firms use unbalanced learning mechanisms, heavily based on external sources of knowledge, including using blockchain specialized firms on the implementation phase. However, Galati et al. (2021) only evaluate the facilitating role of such mechanisms to adoption of external technology to use in their production and commercial activities, not in their innovative capabilities to create new knowledge.

More broadly, existing literature produce mixed findings regarding studies over how firms’ capability accumulation paths are affected when radical and disruptive technologies emerge. While a group of researchers point to the declining performance of incumbents in the

face of radical (ABERNATHY AND UTTERBACK, 1978) and architectural (HENDERSON AND CLARK, 1990) innovation, arguing that organizational inertia (HANNAN AND FREEMAN, 1984), arise from their own cumulative path, as the former successful capabilities may act as constraining elements, as firms create structure and routines to support their capabilities. On the other hand, other scholars argue that existing capabilities are important mechanisms in absorbing such technologies, contingent to managerial ability in conducing organizational changes, creating an ambidextrous organization (TUSHMAN AND O'REILLY, 1996), such as in the case of Polaroid (TRIPSAS AND GAVETTI, 2000), and the successful adoption of cloud computing in Chang et al. (2019). Notwithstanding, the role of capability accumulation in determining firms' innovative output in emergent digital technologies, such as blockchain is wanting.

Therefore, there is a dearth of studies examining firms' blockchain-specific capability-accumulation processes. This study proposes an advance on capability accumulation research in blockchain technology, drawing on existent literature to sustain a set of arguments. First, although some blockchain enthusiasts propagate blockchain as the substitute for traditional firms (through proliferation of Decentralized Autonomous Organization), I argue that it is important to study blockchain initiatives in firms as these organizations hold resources and capabilities to shape the technology's path and general adoption (FAGERBERG, 2005). Second, it is important to understand how firms create their innovative capabilities in this technology, given it is a significant factor in determining the variance in firms' performance and survival (FIGUEIREDO, 2001; NELSON AND WINTER, 1982). Third, blockchain has the potential to disrupt with traditional arrangements as highlighted by institutional theorists (e.g., DAVIDSON, DE FILIPPI AND POTTS, 2018; ROECK ET AL., 2019; AND ALLEN, BERG AND MARKEY-TOWLER, 2019). Consequently, there are some particularities that make this technology different from industrial technologies, with emphasis on the organizational dimension of blockchain (ALLEN et al., 2020). Fourth, studying blockchain initiatives in latecomer firms is important for understanding how capability building processes occur in emerging economies (FIGUEIREDO, 2001; BELL AND PAVITT, 1993), especially in large companies such as Petrobras (DANTAS AND BELL, 2011). Fifth, as an infant technology, blockchain research does not count with long-term observations such as in Dantas and Bell (2011), Kim (1997), and Figueiredo (2011), among others, who collected decades-long data. Therefore, it is a limitation for historical research, which might be mitigated by delineating clear phases in each case study, increasing the possibilities for analyses of variation

within and between them. Finally, while studies mentioned in previous arguments are mostly consolidations of empirical observations at the firm-level, organizational learning starts at individual level (NONAKA AND TAKEUCHI, 1995) when the company is its first steps of the accumulation path. Such spiral behavior of organizational learning is present in Hyundai's path from imitation to innovation, through proactively created crisis at the "team level" (KIM, 1997).

The objective of this study is to identify how latecomer firms develop their initial blockchain-specific capabilities, and it holds on to the mentioned premises to propose the following research questions.

RQ1: What are the blockchain-specific capabilities accumulated by latecomers through blockchain innovation projects?

Firms need to build a set of specific capabilities to innovate with blockchain. Furthermore, the variated configurations, different distributed ledger frameworks (e.g., Hyperledger, R3 Corda, Ethereum), and the plurality of technologies embedded in a blockchain application, increase the challenge to identify and accumulate the necessary knowledge to undertake innovative activities. Moreover, the accumulation of innovation capabilities is far from unidimensional, reaching technical learning and organizational changes that allows latecomers to achieve competitive advantages and make their transitions from imitators to innovators (DUTRÉNIT, 2000). Notwithstanding, the cumulative path might face discontinuities (FIGUEIREDO AND BELL, 2012), especially when radical or disruptive technologies are introduced to markets. In addition, such technologies might demand fundamental changes in incumbents' capabilities, in order to remove "rigidities" and impediments (LEONARD-BARTON, 1992). Therefore, the creation of initial blockchain-specific capabilities might be facilitated or hindered by latecomers' existing capabilities.

RQ2: How latecomer firms develop their initial technological capabilities for blockchain innovative activities?

Firms are most successful in their innovative activities when they manage to integrate their internal and external sources of knowledge (CHESBROUGH, 2003). In the case of Blockchain, there are some possibilities of acquiring external knowledge and resources, through kickstarting their projects using applications on top of a public blockchain, or by subscribing to one Blockchain as a Service (BaaS) provision. Both implementation models can provide acceleration to involved teams in an innovative project, as they count on fixed frameworks and

ready-to-go cloud infrastructure. However, acquired knowledge is not assimilated immediately, and firms still need to develop their capabilities to merely use external knowledge, such as the ones regarding evaluating, architecting, and guiding new technology implementation (CHESBROUGH, 2003).

RQ3: What are the business outcomes obtained by latecomer firms after implementing their blockchain projects?

Finally, it is important to understand at some level what are the returns over investments made by latecomers in blockchain technology. The literature suggests that successful blockchain implementation and adoption leads to reductions in transactions costs (RECK et al., 2020), and improved control over firm's assets (PAN et al., 2020). However, as many studies listed in this review do not disclose if the blockchain-based innovations were deployed to real-world applications, generating economic value, or what firms had obtained any financial revenues or gains in social capital.

3. THEORETICAL BACKGROUND

3.1 Innovative Capabilities

The relationship between a firm's special competencies and firm performance is embedded in some classic management treatises (HOSKISSON et. al, 1999), such as the works of Selznick (1957), Andrews (1971) and Ansoff (1965), which touched the subject, identifying "distinctive competencies". However, Penrose's (1959) seminal book pioneered the idea of firms as bundles of resources in her theory of the growth of the firm. Penrose viewed the firm as more than an administrative organization, but as a collection of productive resources, used over time in different ways by managers. Moreover, she argued that resources are idiosyncratic and heterogeneous, which is central in Resource-based view (RBV) theory. This literature had received little attention over the decades, with few exceptions (RUBIN, 1973), until early 1980's. According to Wernerfelt (1984), the reason was the difficulty to define resources properly, and to address "the unpleasant properties (for modelling purposes) of some key examples of resources". From this period, the precise identification of firms' resources and their performance has been objective of many studies (HOSKISSON et. al, 1999). Wernerfelt (1984), proposed analyzing resources from Porter's (1980) five competitive force framework, shifting the lenses from the product-market perspective. Moreover, he defined resource position barriers, which are "partially analogous" to entry barriers, proposed first mover advantages and a resource-product matrix (another analogy, this time to the growth-share matrix), and discussed exploitation and development of new resources. Although Wernerfelt's (1984) article was rather abstract, it opened a new ground for later researchers on which to build (HOSKISSON et. al, 1999).

In 1991, Barney presented a more concrete and comprehensive framework to identify the needed characteristics of firm resources in order to generate sustainable competitive advantages (BARNEY, 1991). Value is conceptualized as the fitting between firm's combination of resources and external environment so that the firm is able to exploit opportunities or mitigate threats. Rareness is related to the difficulty to obtain resources in the factor markets. Inimitability is the continuation of imperfect factor markets via information asymmetry such that resources cannot be obtained or recreated by other firms without a cost disadvantage. Lastly, competitors, at lower or higher costs, might substitute a firm's combination of resources. However, Barney's (1991) framework still does not address how companies obtain and develop these resources. Moreover, as Wernerfelt (1984) and Penrose

(1959) before, the definition of resources is vague, and the framework is criticized as tautological (KRAAIJENBRINK, SPENDER AND GROEN, 2010). Nonetheless, researchers tried to address these limitations, advancing the theory by specialization, and creating sub-streams of research (HOSKISSON et. al, 1999).

One important sub-stream to understand capability creation is the knowledge-based view of the firm. Kogut and Zander (1996) argued that firms are repositories of capabilities in which individual and social expertise is transformed into economically valuable products. Contraposing transaction costs theory (WILLIAMSON, 1975), they argue that firms exist not only to control for opportunistic behavior, but because they also provide a social community of voluntarist action, structured by organizing principles in such way that the whole is different from the sum of the parts. Moreover, firms provide a social identity to individuals, and coordination mechanisms that lead to social knowledge (KOGUT AND ZANDER, 1996). This means that by its tacitness and social complexity, a firm's stock of knowledge is an important determinant of its competitive advantage (HOSKISSON et. al, 1999).

Associated with knowledge-based view of the firm theory, other studies deepen the understanding of knowledge accumulation, and the way firms develop their innovative capabilities, which allow them to obtain new resources or recombine the ones already available. For instance, Cohen and Levinthal's (1990) "absorptive capacity" refers to the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends, and Teece et al.'s (1997) dynamic capabilities are developed through continuously monitoring opportunities and threats, "enhancing, combining, protecting, and, when necessary, reconfiguring the business enterprise's intangible and tangible assets [i.e., resources]". Moreover, these theories also suggest that organizational knowledge has path-dependent and accumulative features, in such manner that the more resources and capabilities a firm has, the bigger is its potential to get more in the future (COHEN AND LEVINTHAL, 1990).

Various methods exist to measure innovative performance. Most traditional indicators include patent citations and R&D expenditures; however, those indicators are problematic to analyze innovative activities in emerging countries. Instead, several studies use maturity levels frameworks to overcome such impediments, by employing a qualitative assessment of innovative capability levels based on 'revealed capability'. This approach encompasses diverse activities, from minor adaptations in existing technologies and production systems, to engineering-based, research and development (R & D), and patent activities to understand the innovative technological capability-building process (BELL AND PAVITT, 1995; BELL AND

FIGUEIREDO, 2012). Moreover, it allows the auditing of the capability stock of a firm against a benchmark.

Differently from a variety of studies, which combine many innovative aspects in levels (LALL, 1987; BELL AND PAVITT, 1995; FIGUEIREDO, 2001), this study intends to disentangle the technical from the organizational dimension, proposing a classification framework to best understand blockchain capabilities. This approach is described by Bell and Figueiredo (2012) when discussing over the importance of the identification of both dimensions to understand how firms' capabilities progress from lower levels to support incremental innovation to upper levels and enables firms to reconfigure their resources to respond to changes. Figure 2 illustrates an adaptation from Dutrénit's (2000) perception that organizational changes are necessary knowledge management mechanisms for more advanced levels of technological capability-accumulation.

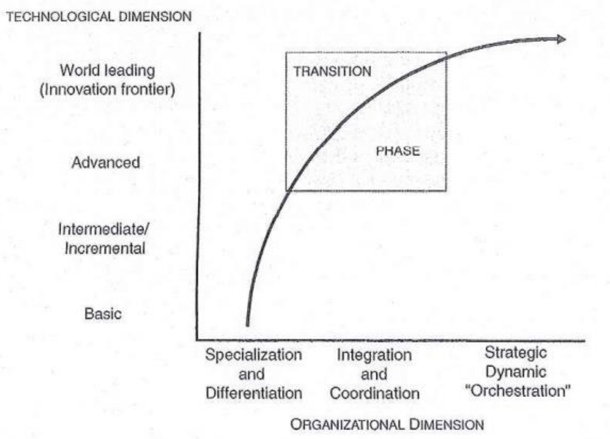

Figure 2: Innovative Capabilities Dimensions
Source: Bell and Figueiredo, 2012; Dutrénit, 2000

According to Dutrénit (2000), there is no simple linear progression from early accumulation stages to the management of knowledge as a strategic asset. Instead, there is a complex transition process as firms build "embryonic strategic capabilities" on top of minimum levels, obtained in early stages. Making a successful transition from imitators to innovator depends largely on firms' abilities in creating a coherent knowledge base through intensive efforts in converting individual learning into organizational learning; effective coordination between different learning strategies; continuous integration of knowledge across organizational boundaries; and stable knowledge creation processes (DUTRÉNIT, 2000).

3.2 Learning Efforts

Organizational learning is a time-consuming process, which depends on the amount of effort invested on it (COHEN AND LEVINTHAL, 1990). Although learning activities include acquiring external expertise from external sources, there are no guarantees that such information will be inserted into firms' stock of knowledge (BELL AND PAVITT, 1993). In fact, importing knowledge from developed countries is widely used in emerging economies but, even so, they still lagging behind, and this is because they are only acquiring part of the knowledge. Polanyi's (1968) famous assertion that "we can know more than we can tell" offers an explanation to why latecomer firms fail in developing their capabilities by only relying in explicit, codified knowledge. Although codified information, such as scientific knowledge, patents and engineering design are important sources, they still need to be absorbed by individuals, who internalize this information by experiencing, creating tacit knowledge. Moreover, knowledge is transferred from the individual to the organization in a continuous manner, by socializing it with other individuals and recodifying external knowledge (NONAKA AND TAKEUCHI, 1995). Such continuous activities are a representation that tacit knowledge is much slower to be transferred and demands large efforts from the organization (KOGUT AND ZANDER, 1996).

Besides effort, organizational learning is also a product of organizations' existing capabilities (COHEN AND LEVINTHAL, 1990). Therefore, it is expected that firms with efficient networks, for example, to count on it to identify opportunities to acquire information, or to create new knowledge in joint innovative activities. Additionally, firms who had high qualified personnel, or an effective R&D department, are expected to create and transfer knowledge more efficiently, given the investments made.

Therefore, I draw from Figueiredo and Cohen (2019) and Cohen and Levinthal (1990), I use three constructs to define learning effort as follows: existing capabilities, internal learning mechanisms and external learning mechanisms. Such division is enlightening to understand blockchain capability creation in organizational and technical dimension as proposed before.

3.2.1 Existing non-blockchain capabilities

Studies regarding catch-up theory focus on how latecomer firms develop their innovative capabilities to pass from imitation to innovation (e.g., KIM, 1997). Such studies show the cumulative nature of organizational capabilities by narrating how these firms build new knowledge on top of the existing knowledge base through intensive learning efforts. Likewise, Teece et al. (1997) show that firms depend on their capabilities to acquire more

resources (including knowledge and skills) or reconfigure them to achieve competitive advantage. Therefore, there are many indications that firms' current capabilities largely affect the way they obtain or create new knowledge to continue in their cumulative path (COHEN AND LEVINTHAL, 1990).

However, institutionalization of practices often leads to 'organizational inertia' (TUSHMAN AND O'REILLY, 1996) in the face of environmental changes, such as the emergency of radical technologies. Leonard-Barton (1992) emphasizes the resistance faced by new product and process development projects due to rigidities stemmed by firms' existing capabilities, especially when such projects introduce changes not aligned with firms "core competences". Notwithstanding, blockchain is often theorized as disruptive in many ways, including potential institutional disruptions of the firm itself (ALLEN et al., 2020). Although this perception may be influenced by the noise created from all hype around it, blockchain technology can also disrupt cumulative capability building paths, or creating discontinuities in capability accumulation. Moreover, the rising of Bitcoin, blockchain communities and decentralized autonomous organizations to mainstream might indicate more deeply changes in economic institutions (DAVIDSON, DE FILIPPI AND POTTS, 2018). On the other hand, there are many consortia established by major players in a variety of industries, which indicates that firms are applying their resources to acquire capabilities in this new technology. Therefore, investigating the role of existing capabilities in innovative blockchain projects might serve to elucidate how Petrobras is absorbing this knowledge and if there are any discontinuities in their knowledge accumulation.

Leonard-Barton's (1992) framework will be used to operationalize the existing capabilities (Figure 3). According to her, four dimensions are important to identify capabilities: i) employee knowledge and skills, which encompass both "firm-specific techniques and scientific understanding"; ii) technical systems, which contain knowledge from several years of accumulating, codifying and structuring tacit knowledge in the workforce; iii) managerial systems, which represent formal and informal ways of creating and controlling knowledge; and iv) values and norms, which are representations of corporate culture. Existing capabilities will be classified as **accelerators**, if they act as facilitators for knowledge acquisition, creation and accumulation, or for achieving business outcomes. Otherwise, such capabilities will be classified as **impediments** if they harm any of the factors mentioned above. Such classification will be used in order to simplify Leonard-Barton's (1992) classification of core capabilities and

core rigidities, as such definition could generate confusion with how capabilities are conceptualized in this study.

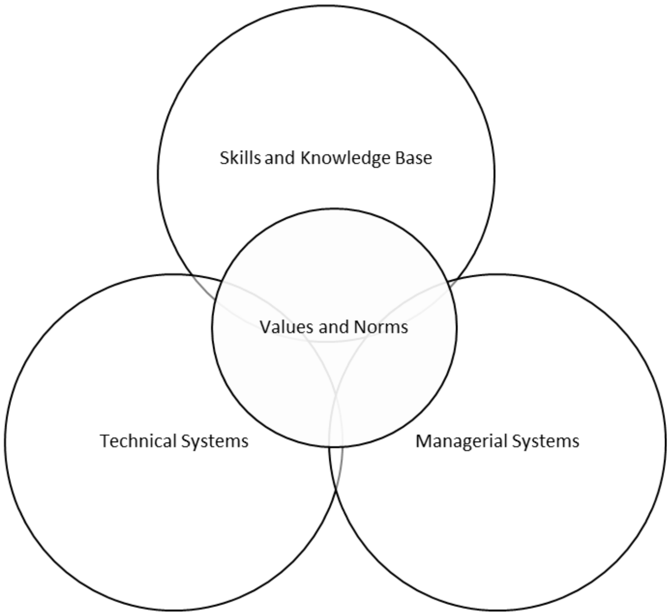

Figure 3: Capabilities' four dimensions.
Source: Leonard-Barton (1992)

3.2.2 Learning Mechanisms

Blockchain technology offers disruptive possibilities of value creation if firms can assemble the necessary resources and skills to build innovative solutions. Especially in developing countries, it might be one of the drivers for latecomers to compete in international markets. However, the current lack of long-term experience with the Blockchain is aggravated by the fact that the technology is not yet mature (TREIBLMAIER, 2019). Consequently, blockchain projects still present large percentages of failure (MALONEY, 2018). Therefore, investigating how firms develop new technological capabilities to create new blockchain-based products and services is timely. Moreover, as a technology for networks, interactions between firms are more salient because they need to contribute, stablish inter-firm governance rules, or even automate inter-firm processes. Thus, it seems important to address how they learn with each other and how they engage in co-creative dynamics. Notwithstanding, the role of internal knowledge sources cannot be overlooked, especially in cases of mode advanced innovations where much experimentation is required to successfully create innovative products and processes.

This study uses the classification frameworks proposed by Figueiredo and Piana (2018) and Figueiredo and Cohen (2019) to classify the initiatives undertaking by latecomer firms to

obtain external knowledge and to create and disseminate new internal knowledge, which they called external and internal learning mechanisms, as explored below.

3.2.2.1 External Learning Mechanisms

Individual enterprises are not isolated actors in the process of technological accumulation. Technical change is generated out of complex interactions between firms, whether by acquisition, in suppliers-customers relationship, or in collaboration arrangements between competing as well as complementary firms, and these linkages are important institutional structures within which firms can interact in creating and improving the technology they use (BELL AND PAVITT, 1993).

The literature on innovation demonstrates that developing capabilities involve different forms of intra- and inter-firm decentralization, from the subcontracting of specialized supplier firms within production networks (SCHMITZ AND STRAMBACH, 2009) to managed knowledge flows across organizational boundaries (CHESBROUGH., 2003). Some producers may collaborate with other firms to develop specialized components of production systems or may engage in dependent suppliers of knowledge-intensive services to undertake aspects of innovation projects (BELL AND FIGUEIREDO, 2012). These interdependencies reflect the nature of learning by interaction, which involves industry downstream and upstream linkages (MALERBA, 1992), cooperation with universities (BELL AND FIGUEIREDO, 2012), and even with competitors (NALEBUFF AND BRANDENBURGER, 1997).

This study operationalizes External Learning Mechanisms, by using the framework proposed by Figueiredo and Piana (2018), as illustrated in Figure 4. As external learning mechanisms, learning linkages are represented as developing through stages, usually evolving from informal to formal links, with some steps between. Vedovello (1997), proposes a framework with three linkage levels between firms and universities: a) informal (e.g., personal contact between staffs, access to specialized reports, access to R&D department, access to educational and training events); b) human resources (e.g., involvement in projects, internship, formal training); and c) formal (e.g., consultancy, analysis and testing, joint research, research contract). Furthermore, Fagerberg (2005) shows that learning linkages have progressive formats, from imitation, problem solving, experimentation, to different stages of R&D.

As in any case of Blockchain innovation, firms need to learn how the technology can be implemented and developed. It is also important to know the proper use cases for each firm. In this way, the capability-building path is similar to other information system technologies, and

traditional linkages with suppliers and universities can be used. However, Blockchain is a technology for networks, which means that organizations participants in a Blockchain application are often sharing resources and automatizing inter-firm decisions. For example, Walmart implemented a Blockchain in its supply chain for specific products and countries. They collaborated with suppliers and government officials to implement a tracking solution, not only changing their own processes, but also their suppliers' processes. Moreover, after proving the concept, they brought big players in the industry, like Unilever and Nestle to co-innovate and develop their network (LINUX FOUNDATION, 2019). In this case, as in many others (LINUX FOUNDATION, 2020; ETHEREUM FOUNDATION, 2020), peers formed networks, and collaborated with each other to find solutions. Although the literature on Blockchain capability building is scarce, and empirical cases are almost non-existent, I argue that, because of Blockchain nature as a technology for networks, there is a special case of learning, which is not limited to transferring, but demands interaction and co-innovation between peers. This is a two-folded argument, on one hand, firms need to build capabilities that facilitate inter-firm collaboration, not only interacting with a technology supplier, but also with different peers, such as competitors, clients, communities, and public agents. On the other hand, technology know-how seems less important than other skills such as making alliances, managing legal constraints, and product development, thus, demanding a diverse skill set from organizations.

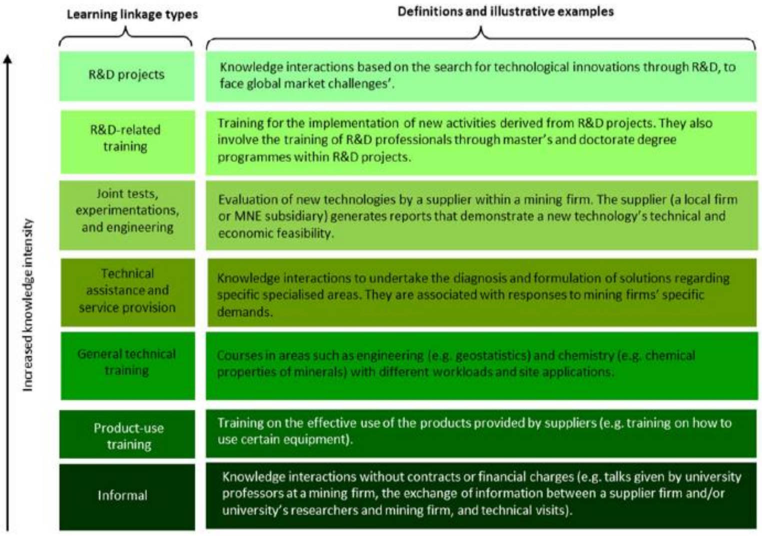

Figure 4: Learning linkages classification framework.
Source: Figueiredo and Piana, 2018

3.2.2.2 Internal Learning Mechanisms

Lewin et al. (2011), show that balancing both internal and external sources are important to knowledge accumulation and creation. In fact, internal learning mechanisms are important

to innovation in developing countries and science-based industries (e.g., pharmaceuticals and chemicals), where firms build R&D facilities and conduct activities that lead to internally developed products that are then distributed by the firm (CHESBROUGH, 2003). Zollo and Winter (2002) show how internal knowledge sharing, integration, and codification are critical to development of higher order dynamic capabilities.

A recurring problem in the latecomer literature is that knowledge absorption is mainly focusing on the acquisition of external knowledge in detriment of internal knowledge creation (BELL AND FIGUEIREDO, 2012; FIGUEIREDO AND COHEN, 2019). Among exceptions, Figueiredo et al. (2020), found that subsidiaries' internal capabilities and internal knowledge mechanisms were important in the context of natural resource-intensive industries, such as bioethanol production. Moreover, Figueiredo and Cohen (2019), found similar results in Brazilian forestry and pulp industry. Although not focusing on internal learning mechanisms, Dantas and Bell (2011) comment on how Petrobras invested in building internal knowledge base, through "sending personnel to trainings and experimenting with the development of new equipment from scratch" (p. 1579), which is in line with activities in examples given by Figueiredo and Cohen (2019).

Figueiredo and Cohen (2019) list of internal learning mechanisms is used in this thesis for operationalization of the construct (Table 2), which "involve search, experimentation, training, and research", complementing external knowledge acquisition in internal capability accumulation processes by reinforcing the absorption of external knowledge, and creating the knowledge base for further external knowledge acquisition and internal knowledge creation.

Table 2:Internal Learning Mechanisms

Specific descriptors	**Examples**
Training & experimentation	Various training form (e.g., classroom, on-the-job) and experimentation (e.g., skill or knowledge building as a by-product of particular innovative experiments; some depend on formally managed processes of exposure to experience-rich opportunities (e.g., searches, non-R&D experiments and fields tests, production and forest sites, and systematics R&D) creating new skills and knowledge.
Knowledge sharing	Internal knowledge exchange (e.g., 'sharing' of what may have been tacit or located in isolated organizational units (e.g., formal/informal meetings, workshops, and seminars to discuss innovative projects and/or solve problems and multidisciplinary teams to exchange knowledge to solve /frame firm's problems/projects).
Knowledge integration	Internal arrangements to integrate knowledge across different technological areas across the firm (e.g., multi-disciplinary teams, innovation committees, and company-wide projects to chare and integrate innovative knowledge).
Knowledge codification	Internal practices by which individual and organizational knowledge is accessed and disseminated to support innovative activities throughout the firm (e.g., routines/procedures for activities resulting from experiments and related activities. Protocols for engineering and forestry activities, storage of learned experiences, internal seminars, elaboration of training modules by in-house personnel, triggering knowledge sharing/integration).

Source: Figueiredo and Cohen, 2019

3.3 Blockchain

Blockchain became popular because of Bitcoin and the seminal paper of Satoshi Nakamoto, which describes the combination of many known technologies, such as cryptography, digital signatures, distributed databases, peer-to-peer connections, and consensus algorithms. Combined with an innovation, a ‘block-based’ data structure, in which groups (or blocks) of transactions are linked to each other by their respective hash code, these technologies could enable tamper-proof exchanges between peers without any third party involved to validate it (BECK et al., 2017). Instead, the validation is performed autonomously by coded scripts, which derives the ‘trustless’ aspect of these applications, as individuals are not making transactions depending on how much they trust each other (WERBACH, 2018).

Most of blockchain characteristics are associated with public networks such as Bitcoin and Ethereum. The Bitcoin Network is a decentralized network (i.e., not controlled by anyone), in which users can transact with each other, transferring the control of a digital asset. Users can also count on coded scripts to validate transactions before they are committed, and on a consensus mechanism to prevent double-spend. Such mechanism works through distributing a block (i.e., a group of transactions) to several peers who receive economic incentives to validate the transaction. In Bitcoin, these peers are called ‘miners’, and the enforcement to compliance is done through rewarding the miner who puts more computational power into a predefined task, which is a consensus mechanism called ‘Proof of Work’ (PoW). After this block is validated, it is updated into the ledger, which is a distributed database (i.e., every member of the blockchain network holds his own copy or can access it in the open cloud). Additional security is possible due to extensive use of cryptography and to the fact that once a block is written in the ledger it is immutable, thus impossible to be changed or deleted (except by a major change, called ‘fork’, which needs to be supported by a large contingent of members in blockchain community).

Swan (2015) calls Bitcoin and other contemporary cryptocurrencies as the age of Blockchain 1.0, because of the restricted use of a network just to transfer the possession of a digital record between users. After Bitcoin became public, Buterin published Ethereum’s white paper, arguing that Blockchains could go further, proposing a Turing-complete virtual machine, capable to run code in several programming languages and with different purposes (MOYANO AND ROSS, 2017). These codes are also called ‘smart contracts’ and are responsible for conveying greater flexibility into the technology, allowing individual developers, communities

and firms to create blockchain-based solutions to several problems and business cases. Moreover, the increasing possibilities attracted the interest from major players, such as IBM, JPMorgan, Amazon, Cisco, Microsoft, Amazon, among others, who started to form consortiums to create their own technologies, aiming to create blockchains for organizations (e.g., Hyperledger, R3 Corda, Ripple). These configurations allowed firms to stablish private networks with restricted access, which in turn made possible to use lighter consensus mechanisms, given that neither actors are anonymous, nor the access is public. Although eliminating core blockchain features should restrain some envisioned benefits, permissioned networks removed early technical limitations in their public counterparts, such as lower throughput, high energy consumption, security, and data privacy (BECK, MÜLLER-BLOCH, AND KING, 2018). Table 3 lists the types of blockchain networks that are possible.

Table 3: Typology of Distributed Ledger Technologies

Access to transactions	**Access to transaction validation**	
	Permissioned	Permissionless
Public	All nodes can read and submit transactions. Only authorized nodes can validate transactions.	All nodes can read, submit, and validate transactions.
Private	Only authorized nodes can read, submit, and validate transactions.	Not applicable

Source: Beck, Müller-Bloch, and King, 2018

Treiblmaier (2019) argues that a permissioned network run by members of a consortium, for example, represents a rather closed ecosystem with clearly defined participants and control structures that are partly centralized, and list some repercussions of this setting, such as privacy, throughput, and the choice of consensus mechanisms. Permissioned and private networks usually are more controlled environment and tend to be less prone to attacks among members, therefore some of more rigorous constraints, such as using the costly PoW consensus, are replaced for more efficient mechanisms to increase throughput and reduce costs (MARSALEK et al., 2019). Furthermore, security issues are addressed by delegating the network management to a consortium or independent third party, having more rights than other actors. Transparency has also a different perspective in such configurations because private users might be concerned about sensitive personal data, and organizations might fear the leakage of confidential financial information (TREIBLMAIER, 2019). Therefore, the “trust” factor in permissioned and private networks does not fully reside in the Blockchain and smart contracts. Instead, there are some

complementary agreements outside the network, such as traditional contracts among participants (MARSALEK et al., 2019).

3.4 Blockchain Innovation Dimensions

Firms need to build a set of specific capabilities in order to innovate with blockchain. Furthermore, the variated configurations, different distributed ledger frameworks (e.g., Hyperledger, R3 Corda, Ethereum), and the plurality of technologies embedded in a blockchain application, increase the challenge to identify and accumulate the necessary knowledge to undertake innovative activities. For example, Moyano and Ross (2017) proposes a Know-Your-Customer (KYC) blockchain application to banking firms, which would also include a regulator, such as a national Central Bank. Their research was a product of a hackathon with IT University of Copenhagen, resulting in a solution with three major variations: i) a permissioned network on top of Hyperledger Fabric framework, controlled by a consortium of banks, with privileged access to the Regulator; ii) a public network using Ethereum network, without privileges to the Regulator; and iii) a centralized solution provided by the Regulator. They argue that using blockchain generally would reduce costs in processing KYC requests and in auditing, but there were significant differences between the proposed implementations. It is important to notice that the reported actors (firms, universities, and government) made considerable efforts, engaging in joint research activities just to merely understand the problem and its possible solutions, let alone all the remaining activities and knowledge required to implement such innovation in the banking national system.

Firms need to master two dimensions when undertaking innovative activities with blockchain, the technical and the organizational. These two overarching domains stem significant variation in the capabilities needed to understand the reason **why** the firm is implementing or developing a blockchain-based application, and those required to know **how to** implement it. Given the options available, the diverse technical knowledge required to deal with the components of each framework, and the variated maturity levels, one should not be shocked with the large efforts made by firms, such as reported by Moyano and Ross (2017).

3.4.1 Blockchain Technical Dimension

A Blockchain application can be generally structured in layers, as illustrated in Figure 5 (MENG AND QIAN, 2018). The data input layer defines the source of raw input data that can be used in subsequent layers. It could be recorded manually, automatically by coded rules or captured via IoT devices, such as sensors. For example, Vortex Blockchain is a solution for oil and gas bulk liquid distribution supply chain, which uses IoT sonar sensors placed on

propane tanks to provide real-time information about customers' stock of heat gas. In addition, they also monitor the weather to predict disruptive climate conditions in cold places, such as a polar vortex (IBM, 2019). Another example, Tracr is a provenance solution to track and trace diamond's supply chain, which is controlled by major players in the industry, and is currently in a pilot stage. They work with manual inputs from diamond producers, manufacturers, and polishers, which they call 'declared' information, such as color and fluorescence. Additionally, they also collect data via 3D-scans, which they call 'verified' data, to enrich provenance information (TRACR, 2020).

After capturing the raw data input, the system formats them into a data structure called 'transaction', which is immediately created, and then broadcast to the network for verification. In the Smart Contracts Layer, the transactions are validated and/or transformed, whether by disaggregating data, formatting or aggregating more information from external sources. Also known as 'Oracles', these external 'trusted' sources can be from various origins, such as IoT devices, software, and even human experts, and their function is to provide 'off-chain' data to smart contracts execution. Alternatively, Oracles might function to export data from the blockchain to external sources. Notwithstanding, the presence of Oracles represent higher risks and necessity for adaptations, resulting in learning-by-doing dynamics. As highlighted by blockchain expert Martha Bennett, blockchain's architecture enhances security and enables distribution of trusted data across organizational boundaries, however the technology cannot "ensure that the data that's being notarized or captured is accurate and truthful", "ascertain the real-world legal ownership status" of a digital representation of an asset, or "ensure the continued integrity of the physical goods as they move along the supply chain, and it can't prevent tampering with source data (e.g. from a sensor)". Moreover, she argues that all these external, 'off-chain' information need to be handled by controls, processes, and technologies other than blockchain, which creates greater demand for multiple knowledge and skills (IBM, 2021).

Drawing from Meng and Qian (2018), I illustrate the Ledger Layer as the consensus mechanism which verifies the 'correctness' of transactions, groups them into blocks and adds new blocks on the distributed ledger. It starts once a transaction has been created and reached the threshold number of passed verification in the network. At this point, it is an 'unsettled transaction'. In Meng and Qian's (2018) implementation, all unsettled transactions are placed in a distributed pool across the network and wait for next block miner to package all of them into a new block and append into the ledger. A transaction is in a status called "settled" when

it has been associated with a block on the ledger and is thereafter permanently immutable. While educating, this example is just one of the possibilities as different consensus mechanisms exists, depending on the blockchain framework in use (e.g., Ethereum, Hyperledger, Hashgraph). Moreover, the network nodes who validate, the 'miners', might also variate according to the framework and the networks' typology (as in item 3.3 of this thesis). Finally, general blockchain features also variate depending on the implementation, such as 'privacy' settings to regulate who can access the data from the ledger (therefore, not transparent) and even 'state' controls to allow blocks to be changed or deleted after committed to the ledger (thus, not immutable).

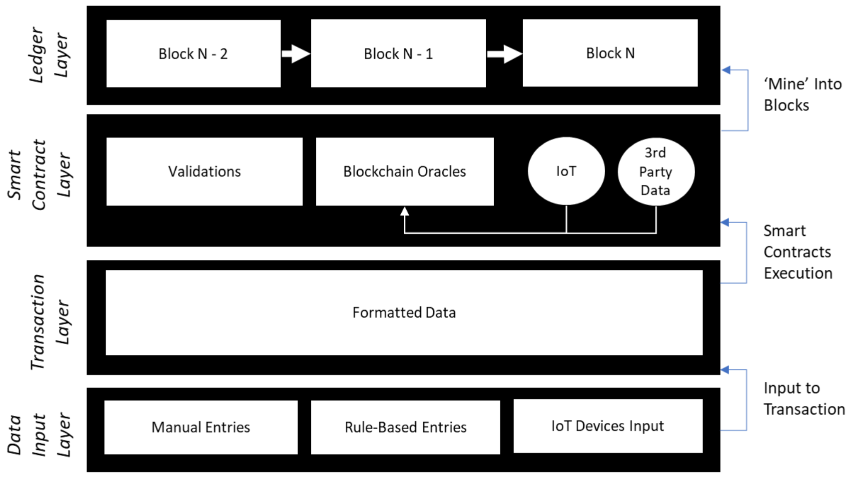

Figure 5: Blockchain Application Layers
Source: adapted from Meng and Qian, 2018

Even though Figure 5 fairly depicts a conceptual blockchain application, the different **typologies** (private, permissioned, public) and **frameworks** offer a wide range of possibilities. Moreover, **off-chain** integration decisions need to be considered to cases when one network needs to communicate with the world outside it. After having considered these variables, firms need to choose their **implementation model**, which is directly linked to the technical capabilities a firm needs to develop in order to innovate with blockchain.

Implementation models encompass the most suited typologies and adequate frameworks to the desired solution. They range from implementing smart contracts in a public network (such as Ethereum) to designing a new blockchain technology (e.g., one with a new consensus mechanism). Although, developing new blockchain technologies was more prominent in the past, when existing frameworks where very limited, there are still a large room to improve, in order to overcome current and near future limitations, such as energy consumption, disk space and scalability issues. For example, Ethereum community is on a roadmap to launch Ethereum 2.0 milestones, including some releases planned only to 2022 (LINUX FOUNDATION, 2021).

The Linux Foundation, which is supported by major IT companies as members (e.g., AT&T, Cisco, Facebook, Google, IBM, Intel, Microsoft), and is responsible for the Hyperledger frameworks, frequently launches new versions and new tools. These ‘new-to-world’ technical innovations are extremely advanced and are largely restrained to organizations located at the ‘global innovation frontier’ (BELL AND FIGUEIREDO, 2012).

Notwithstanding, as indicated by Bell and Figueiredo (2012), firms can innovate by making more modest technical alterations, through recombining certain components, or adapting the technology to their contexts. First, there are the public blockchain networks, such as Ethereum. In this model, blockchain solutions use a technology already available, therefore demanding a smaller set of capabilities from firms, which is an accelerator. However, firms have small room for changes, which are restricted to coding smart contracts and limited privacy settings (available only in ‘Ethereum for Enterprises’ version) and are forced to adapt to the ‘ways of working’ established by the network protocol. Moreover, Public networks have their own pricing and charging policies, and most of them are ‘tokenized’, which cannot be underestimated when calculating operational costs of a blockchain-based solution.

Second, there are models based on service provision, known as ‘Blockchain as a Service’ (BaaS), which is not restricted to, but is largely dominated by, major cloud-computing companies, such as AWS, IBM, Google, and Alibaba. In this model, almost all efforts to setup and operate a network is outsourced to a third party, who provides accelerators such as cloud-based infrastructure, easier configuration of network nodes and protocols, and ready-made blockchain-based software products. For example, IBM Blockchain Platform allows clients to setup private and permissioned networks on top of Hyperledger Fabric framework, configure privacy settings and quickly create network nodes. Alternatively, Alibaba offers Hyperledger Fabric framework, Quorum and their own blockchain AntChain. Compared with public networks, BaaS model offers more control over configurations and flexibility to use in more business cases. They also work under contractual basis, which offer more predictability over costs, when compared with tokenized services. Although provided with quick-start setups, firms need to understand blockchains more deeply to configure the network as needed, when compared to fixed ‘ways of working’ in public blockchain. There are also considerations about avoiding locked-in situations, given that the firms do not develop their technical capabilities further to sustain their innovations on their own, and security issues.

As Li et al. (2021) observe, BaaS are designed to reduce knowledge absorption of several blockchain features, leaving to customers and developers only tasks related to

programming blockchain applications. Moreover, it reduces the amount of effort and resources dedicated to maintaining the network.

> "Deploying BaaS on cloud computing platforms, customers are allowed to leverage cloud-based solutions to design, develop, and host blockchain applications that can run on top of smart contracts and functions over blockchain networks. Services vendors here can manage all the necessary tasks and activities in order to support agile and operational infrastructures while customers only need to employ BaaS to execute tasks and activities. […] Similar to other systems, blockchain-based applications are developed over the underlying blockchain infrastructure. In this manner, BaaS developers are not required to fully understand blockchain internals but only methods of invoking BaaS services to build a blockchain application. In this way, developers can focus on the business logic of applications while BaaS vendors only need to deploy decentralized applications on top of a blockchain infrastructure."

Third, on-premises implementation model usually takes place when a firm do possess resources and develop more advanced capabilities to choose and internalize a blockchain framework, such as Hyperledger Fabric. In this model, the firm's technical team is responsible to research the best existent alternatives and implement available protocols. The major difference is that, although more demanding in terms of knowledge, IT resources and specialized personnel, it allows higher levels of control and major improvements and customization. In more advanced implementations, firms are able to avoid restrictions imposed by BaaS providers and public blockchain networks. There is also full control over security, costs, and data storage, as data can be stored in third-party or private clouds, or even in data centers. On the other hand, the firm needs to study and deeply understand the technical components of a framework, which encompasses dealing with several embedded technologies. Moreover, as blockchain frameworks are evolving fast, the firm needs to be always up to date. For example, in one of Petrobras projects, the team was working with a set of components there were valid until Hyperledger Fabric version 1.3 (Hyperledger Composer and Kafka), which were discontinued in version 1.4, impacting the ongoing implementation.

The differences between outsourced (e.g., public networks, BaaS providers) and in-house models (on-premises) exemplified by Li et al. (2021), are generally directed to how external sources of knowledge might be used in the form of services to the firm, which relieves them of all learning efforts to implement and maintain blockchain infrastructure. However, there are also limitations with outsourced models (external to the firm) that might constrain innovative activities, even failing in complying with mandatory requisites, such as data privacy or business continuity. In sum, Figure 6 illustrates the hypothesized innovative capability levels when considering only the blockchain technical dimension.

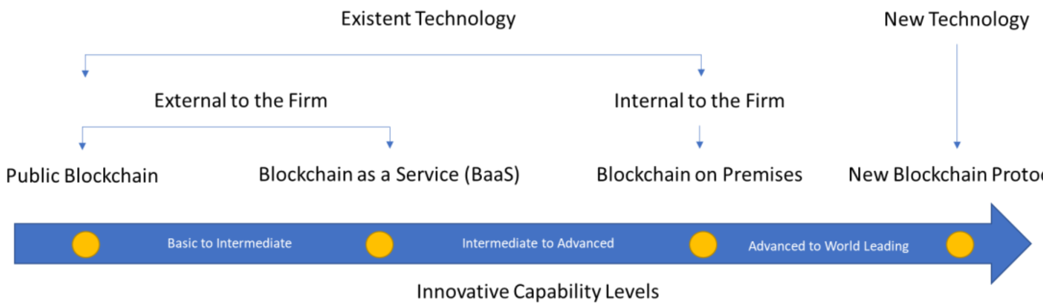

Figure 6: Blockchain Innovative Capability Levels in Technical Dimension

3.4.2 Organizational Dimension

From a firm-level perspective, blockchains are a special type of interorganizational information systems (IOS). The concept of IOS refers to a network-based information system that transcends organizational boundaries (BAKOS, 1991). As an interconnected asset between organizations, an IOS provides an electronic channel through which firms can openly access the information of their partners at lower costs. An IOS-based alliance can reduce communication errors, lower total costs, and fostering greater product differentiation, enabling partners to outperform competitors (VON HIPPEL, 1988). However, cooperation and competition relationships between firms are complex. Even in more stable ecosystems, in which cooperation is critical to ensure the availability of components, firms fight for leading roles and take diverse strategic movements to stablish themselves in bottleneck positions, affecting innovation direction and firms' ability to jointly create value (ADNER AND KAPOOR, 2010; HANNAH et al., 2016).

When analyzing the contributions of IOS to supply chains, Lee et al. (2014) show that visualizing data more clearly leads to higher performance in the whole value chain. Firms were able to work in close coordination and optimize performance across the entire supply chain. Allen et al. (2020), go even further positing blockchain technology as an institutional innovation, which allows firms to change their structure to function around a distributed ledger, with decisions programmed in smart contracts. The authors analyze blockchain technology by the institutional theory lenses, arguing that the validation algorithms decrease opportunism, while transparency diminishes information asymmetry, resulting in lower transaction costs and allowing some economic activities to be transferred from firms to a new institutional arrangement, which is now viable because of the distributed ledger technology.

Knowledge-sharing routines are very important to inter-firm cooperation (DYER & SINGH, 1998), as they permit the transfer, recombination, or creation of specialized knowledge

between partners in a regular flow. Also, effective governance mechanisms are pivotal to reduce uncertainties, to manage interdependencies, and to enhance trust. Many misinterpret blockchain ‘trustless’ aspect as a mechanism to remove this factor from the equation. Although Bitcoin creators claimed that it is “a system for electronic transactions without relying on trust” (NAKAMOTO, 2008), we cannot understand it as there are no need for trusting when we are creating blockchain solutions, especially between firms. In fact, transactions occur because individuals trust in the code that governs the network, ironically resulting in trusting a ‘trustless’ technology (WERBACH, 2018). Moreover, this code is created by humans, who are not free from committing errors, whether honestly or intentionally. We should not forget that technological innovations are often achieved in ‘learn-by-doing’, ‘trial and error’ dynamics, and there are not many guarantees that all possible conditions were predicted by the team which is in charge to develop a blockchain solution.

To reduce risks in IOS development and implementation, firms often recur to joint governance structures, processes, and associated arrangements that IOS management must have in place to fully account for the management of systems and the services delivered (LEE et al., 2014). With the appropriate IOS governance structure in place, investments into relationship-specific capital can be safeguarded, resulting in more collaborative behavior in terms of information exchange. Without the appropriate governance structure, an organization’s opportunistic behavior may cause other partners to behave opportunistically as well (PARK AND UNGSON, 2001), thereby restraining the flow of information between peers. Such governance arrangements are not fully coded in smart contracts or consensus mechanisms. Often, they are largely outside the application, and the most popular form of governance and cooperation is a consortium.

I propose three innovative capability levels in the organizational dimension required for implementing blockchain depending on how much decentralization is embedded in the application, and how much information flow between firms’ organizational boundaries. First, private blockchains can be restricted to internal processes, acting as substitutes for other centralized database systems. Such implementations are entirely controlled by a central actor, and present many features as optional, such as immutability or transparency. They offer more control, safety, and performance; however, they cannot explore blockchain major benefits. In this way, innovative capabilities are more limited, as blockchain technology acts as a secondary feature in a centrally controlled application.

A more advanced capability is required to create blockchain-based IOS such as Consortia. On one hand, consortia represent a lower-risk effort, and it increases benefits from network effects to all partners. However, consortia need good governance structures to facilitate consensus around standardization issues that are in part driven by politics. Gratzke et al. (2017) encountered several different approaches, to convince competitors to collaborate, “including the formation of smaller subgroups to work on delineated issues, and providing several levels of potential engagement, ranging from participation in monthly calls to active technology development”. Therefore, in order to engage competitors and collaborators in a blockchain innovation through consortia formation, firms need to rely on organizational capabilities such as alliance-making. Moreover, there are significant legal concerns with antitrust laws that need attention of firms’ legal department and frequent interaction with regulators (PIKE AND CAPOBIANCO, 2020).

Finally, the most advanced blockchain-based organizational innovation is a Decentralized Autonomous Organization (DAO), also called ‘Blockchain As Organization’ (BAO) or DApp (Decentralized Application). Such organizations are coded based organization, often represented by a foundation or developer community. Examples of this kind of organizational setting are The DAO (which was hacked in 2016, caused immense issues to Ethereum Foundation), Dash (a decentralized cryptocurrency), and Steemit (a social media decentralized App), among others. Although largely restricted to cryptoeconomy sector, such innovations are expected to mature in near future. However, they bring many institutional changes, especially in legal systems, and also in customer support. For example, Decentralized Exchanges (DeX) bring many beneficial features, when compared with centralized exchanges, such as no single point of failure and disintermediation, however, DeXs are likely to face further challenges from regulators, who have signaled that they do not agree with the view that decentralized exchanges should not be subject to the same oversight as centralized rivals because they do not actually hold assets (VERMAAK, 2020). In sum, Figure 7 illustrates the hypothesized innovative capability levels when considering only the blockchain organizational dimension.

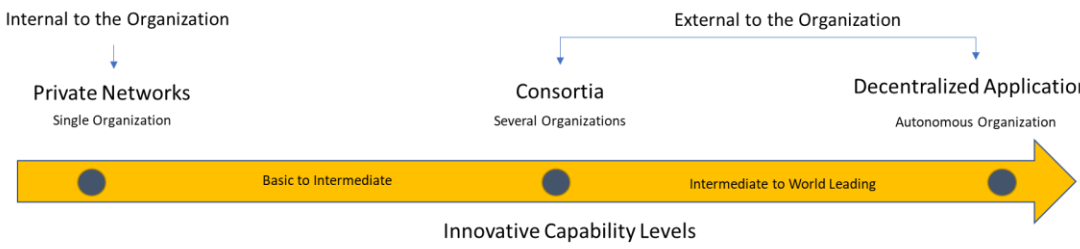

Figure 7: Blockchain Innovative Capability Levels in Organizational Dimension

3.5 Business Outcomes

Organizational performance is not a one-dimensional theoretical construct nor is it likely to be characterizable with a single operational measure (RICHARD et al., 2009). Broadly, organizational performance encompasses positive (or negative) results to firms' stakeholders (mainly shareholders) over a period. While financial results are often used for assessing performance, other variables are used such as customer outcomes, innovation, internal process improvement (KAPLAN AND NORTON, 1996), economic value added (STERN et al., 1995), corporate social performance, among others.

In their perpetual search for increasing performance, regardless of how it is measured, firms invest in projects which might generate business outcomes through creation of specific assets, which allow them to achieve sustainable competitive advantage (TEECE et al., 1997). Such investments might target learning activities, high-uncertain R&D activities and even open-source protocols, such as in the case of Blockchain consortia and foundations (e.g., Hyperledger, Enterprise Ethereum, Corda). For example, one expression that has become popular in blockchain communities is the "fear of missing out", which is a "typical feeling when a new technology arises and people have not a clear idea of its benefits" (TAVIRA, 2020). In other words, faced with high uncertainties by the entrance of a radical technology, firms might invest to learn it, in order to understand better the threats and opportunities. Therefore, such firms are not concerned with short-time financial results, but with their long-time survival by creating their blockchain technological assets.

To operationalize business outcomes obtained from a blockchain projects, this study uses "specific assets" definition in Teece et al (1997), which encompass specialized plant and equipment, difficult-to-trade knowledge assets and they complements, reputational assets and relational assets. Such specific assets determine a firm's competitive advantage at any point in time (TEECE et al. 1997). Table 4 lists the types of organizational assets and some examples.

Table 4: Business Outcomes Framework

Type of Asset	Example
Technological	Know-how protected or not by intellectual property laws.
Financial	Cash flow and balance sheet assets
Reputational	External information about a firm. Consists in an intangible asset that enables firms to achieve various goals in the markets.
Structural	Formal and informal structure of organizations and their external linkages. Also includes hierarchy and governance modes.
Institutional	Assets that facilitate firms' existence in a business environment, such as regulatory systems, property rights, public policies, national level of education
Market	Market share

Source: Teece et al. (1997)

3.6 Proposed Analytical Framework

As shown in Figure 8, I argue that blockchain implementations demand specific innovative capabilities (as described in 3.1), which are accumulated on top of firms' existent capabilities (as in 3.2.1), by the acquisition and assimilation of knowledge obtained through external learning mechanisms, and the creation and dissemination in internal learning mechanisms (as in 3.2.2). Both internal and external sources of knowledge are well-known in then literature (BELL AND FIGUEIREDO, 2012; KIM, 1998) as significant variables to capability accumulation processes. This thesis aims to contribute with Blockchain literature by proposing a categorization of specific capability demands related to Blockchain in two dimensions: technical and organizational (as in 3.4). Such identification and categorization of specific capability demands are useful to understand how capability accumulation processes are being undertaken regarding this technology. Finally, I aim to identify the outcomes through analyzing the implemented Blockchain activities and the benefits to Petrobras (as in 3.5).

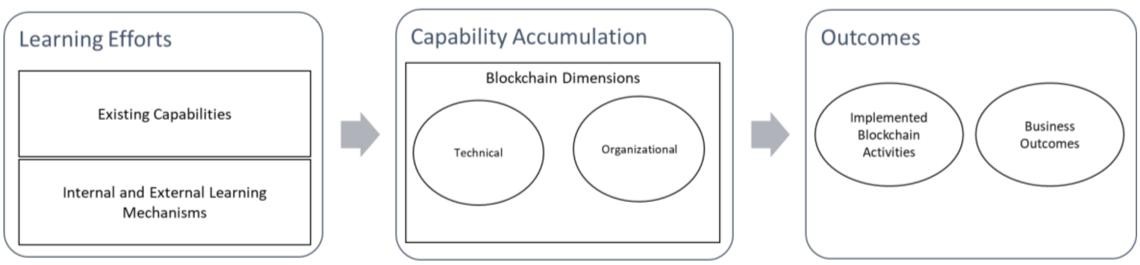

Figure 8: Proposed Analytical Framework of Blockchain Innovative Capability Building

4. EMPIRICAL CONTEXT

Created in 1953, Petrobras is the major Brazilian Oil and Gas company and one of the largest producers in the world. The company is present in several Brazilian states, and other countries, especially in South America (Figure 9), holding activities in Oil and Gas Exploration and Production, Oil and Gas Refining, Electric Energy Generation, Biofuels, Petrochemicals, Distribution, Transport and Trading operations.

Petrobras has pioneered exploration and production on ultra-deep pre-salt areas, acting as world leaders in this kind of technology. As Figure 9 shows, Petrobras' upstream activities are highly concentrated in offshore areas, a characteristic of Brazilian territory, which imposed barriers to oil exploration and production throughout the 20^{th} century. In fact, oil basins where thought to be inexistent in Brazil until 1930's, when the first oil fields were discovered in Bahia. However, onshore reservoirs are significantly smaller than offshore, which compelled Petrobras to develop capabilities to explore and produce in those areas. Moreover, onshore oil fields are much cheaper to build and maintain, thus, Petrobras had to innovate in order to overcome safety and commercial restrictions to grow their offshore operations, while respecting minimum break-even oil prices to finance their projects. Dantas and Bell (2011) show Petrobras journey from imitators to innovators in 11 technologies related to deep waters and ultra-deep waters operations. They emphasize the importance of CENPES (Petrobras' R&D department) in developing knowledge networks with suppliers and universities to create indigenous innovations, and advance Petrobras' innovative capabilities to world leading positions. Moreover, corporate programs undertaken over the last 40 years have created the innovative focus to drive resources and managerial attention to capability building (KIM, 1997), such as PRAVAP (Program of Advanced Recovery of Petroleum) in the 1990's, PROFEX (Program of Technological Development in Exploration Technologies) also in the 1990's, and PROCAP (Program of Technological Development on Deep Water Production Systems), which had repeated versions in the 1980's, 1990's and 2000's.

Figure 9: Petrobras Operations Geographical Distribution
Source: Petrobras (2021)

Recently, Petrobras has faced two important shocks which are directly linked with the cases in this study. First, Digital Transformation has been undertaking oil and gas industry since early 2010's, bringing significant cost reduction through High Performance Computing (HPC), which allows better image from seismic readings. The rapid evolution of this technology has been responsible for better quality in seismic reading and better performance in their interpretations. In 2021, Petrobras has finished their new supercomputer called 'Dragão', which was the 46th supercomputer (TOP500, 2021). Together with previous supercomputer 'Atlas' (94th) and 'Fênix' (129th), Petrobras responds to 50% of the Top 500 supercomputers in Brazil. Moreover, Petrobras' HPC capabilities roughly doubled from 2020 (14,220 TFlops/sec) to 2021 (28,226 TFlops/sec), in order to support two ambitious programs: PROD1000, to support first-oil production in 1000 days after the discovery, and EXP100, to have 100% success in exploratory projects. Furthermore, investments made in HPC capabilities are just one of Petrobras' efforts to digitalization. The company has made organizational changes to accelerate Digital Transformation (Figure 10), such as joining CENPES (R&D) with Information Technologies and Telecommunications (ICT) under the same Directory, which is purposefully named as Digital Transformation and Innovation. In addition, they created an area to specifically foster digital transformation initiatives (called Digital Transformation), and other departments called Centers of Excellence (CoE) to centralize and foster technologies that the company values, such as Robotic Process Automation, Artificial Intelligence & Analytics, and Agile.

Second, the company passed through a severe crisis between 2014 and 2017 due to the results of investigations in the context of ‘Carwash Operation’ (‘Operação Lava Jato’) undertaken by Brazilian Federal Police. The Police taskforce investigated Petrobras and its suppliers and made several denounces of corruption involving the highest ranks of Brazilian authorities, Petrobras’ former executives and other firms in its supply chain. Despite investigations indicated that the company was a victim of criminal activity, suffering damages by the fraudulent scheme, Petrobras’ image and reputation was tarnished, and the company had to respond in several instances, locally and internationally. In response, the company implemented governance and compliance controlling measures. Moreover, increasing scrutiny forced managers to submit reports containing considerable volumes of data, which was time-consuming. Over time, these managers started to search for ways to respond faster and with less effort to increasing controlling, which fostered projects to automatize process, and to enhance speed in data access.

The cases reported in this study are direct reflections of both growing digitalization in Oil and Gas industry and increasing compliance and controlling demands in Petrobras. Moreover, an important endogenous characteristic that stands out and must be considered in the analysis of knowledge building and innovation diffusion is that Petrobras is a big and complex enterprise, with several departments, which often consist in knowledge silos. The company ended 2020 with approximately 49,000 direct employees and 92,000 outsourced staff, in a total workforce of roughly 150,000. In 2013, there were more than 400,000 professionals. Therefore, it is not rare that groups are working in similar initiatives without knowing each other, and there is a significant effort just to mitigate such situations. For example, the centralization of some capabilities (such as ICT-related tasks and projects, or R&D), acts as an organizational mechanism to improve the portfolio of innovative activities, helping to prevent duplication of activities and enhancing integration. To illustrate the argument, Figure 10 shows Petrobras’ organizational chart, which counts with a considerable number of departments.

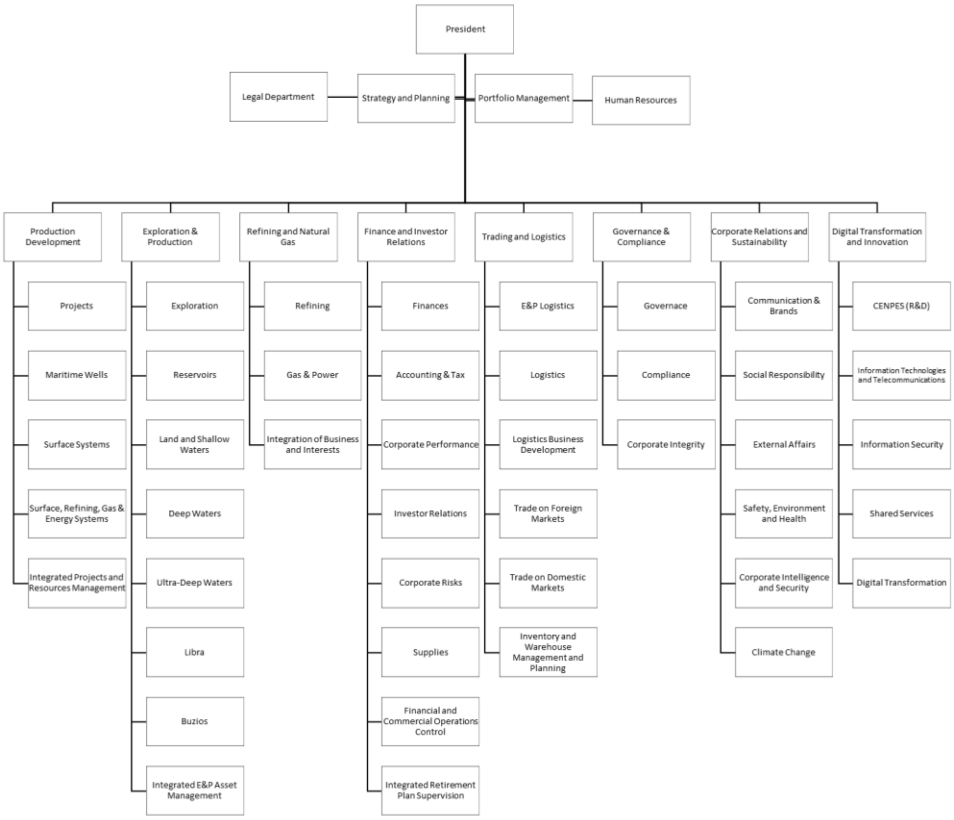

Figure 10: Petrobras’ Organizational Chart

Source: Petrobras (2021)

5. METHODOLOGY

Given the scarcity of studies examining innovation capability building and the underlying interactive learning strategies in Blockchain technology, an exploratory approach is the most appropriate for providing a better understanding of this relationship (SEKARAN, 2003). This study adopted a qualitative and inductive approach, operationalized through a cross case-study research strategy, and substantiated by fieldwork. This methodological approach is considered appropriate in improving the understanding of an under-researched phenomenon, the details of which could be missed by aggregated analyses based on quantitative methods (EISENHARDT, 1989). Through this approach, it is possible to provide insights contributing to theory building through analytical generalization (YIN, 2009).

5.1. Case selection strategy

Researchers choose cases with the characteristics they need for an in-depth understanding of the research question issues (MILES AND HUBERMAN, 1994). Dantas and Bell (2011) highlight the special role of large companies in developing countries in knowledge network creation, as they use their firm-level capabilities to engage in specific learning linkages and develop networks. Moreover, previous studies indicated that Petrobras had built a wide set of networks (DANTAS, 1999), and its experimentations in blockchain technology had been well covered by the specialized press in Brazil (BARROS, 2019; AMARO, 2019). Additionally, Petrobras provides relevant evidence to substantiate the research question, and presents a high chance to generate rich information about the issues under study. Therefore, the selection is based on the specific characteristics of “extreme exemplars” or “polar cases” (EISENHARDT AND GRAEBNER, 2007), providing a powerful example of the phenomenon under study (SIGGELKOW, 2007).

5.2. Data collection

This study applied semi-structured interviews with Petrobras’ leaders, project teams and department leaders, who had collaborated in the two first blockchain projects, which occurred between 2018 and 2021. More specifically, the first efforts of Project Alpha began in 2018, and the project was concluded in 2020, while Project Beta, started in 2018 and finished in 2021.

Fieldwork observations were collected through participations in 12 project meetings, during 2019. In total, 10 interviews were made with 10 interviewees at Petrobras, between April

2021 and June 2021, with duration between 30 and 60 minutes approximately (Table 5). Eight of these interviews were recorded and transcribed, with notes being taken on the remaining.

Additionally, archival data and information available in the literature were used as secondary sources, such as news covering Petrobras' projects in specialized (GUSSON, 2019) and partners' (PUC-RIO, 2019) websites, available documentation, and recent technical literature (PASKIN et al., 2020). Such documents are used for triangulation purposes (MEIJER et al., 2020).

Table 5: Interviews

Interview ID	**Project**	**Interviewee Role**	**Approximated Duration**
1	Alpha	Project Leader	40 minutes
2	Alpha	Team Member	30 minutes
3	Alpha	Technical Leader	30 minutes
4	Beta	Project Leader	60 minutes
5	Beta	Blockchain Architect	60 minutes
6	Beta	Technical Leader	40 minutes
7	Beta	Finance Team Manager	50 minutes
8	Beta	Product Owner	55 minutes
9	Beta	Team Member	35 minutes
10	Beta	Finance Team Leader	60 minutes

5.3. Data analysis process

Evidence collected from interviews together with field notes were organized and attributed to each predictor on the framework illustrated in Figure 8. As described in section 4, Leonard-Barton (1992) framework is used to identify existent non-blockchain-specific capabilities, in which observations are mapped into four thematic categories (Figure 3). Subsequently, I use Figueiredo and Cohen (2019) to classify information regarding internal learning into other four categories (Table 2), and Figueiredo and Piana (2018) to classify observations of external learning as illustrated in Figure 4. Additionally, observations of specialists' opinion, technology providers websites, and data collected at Petrobras to create and map differences in knowledge intensity regarding two blockchain specific technical and organizational dimensions. Both dimensions and scales were used to map knowledge accumulated at each project phase. Furthermore, Teece et al. (1997) list of organizational assets

is used to organize and classify business outcomes into five types of assets (Table 4). To summarize, Table 6 consolidates all observations of each variable above, in order to facilitate data analysis.

Finally, data is analyzed in project phases, which are delimited by major milestones, identified in interviews and archival data. Each observation was mapped to the respective project, and project phase, providing a methodological frame to analyze variation between projects and within each project, by comparing different values in predictors observed in each phase in a simplified timeline matrix (MILES AND HUBERMAN, 1994), illustrated in Figure 19.

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6. FINDINGS

In this section, I present the findings regarding the blockchain capability accumulation process in the context of the first two blockchain projects undertaken by Petrobras, to substantiate the Research Questions. The evidence show here is important to understand how Petrobras created their initial blockchain specific capabilities. Moreover, this study shows the effects of learning efforts in blockchain specific capabilities, and their outcomes to Petrobras, both in terms of its knowledge base increasing, and of business outcomes. In the section 6.1 and 6.2, I present both cases, describing (i) what blockchain specific capabilities were accumulated; (ii) what levels of blockchain specific innovative capabilities were achieved by each project in technical and organizational dimensions; (iii) what innovative capabilities existed before both projects, and how they were used by project teams; (iv) the external and internal knowledge mechanisms were used to absorb and create new knowledge; (v) the project outcomes to Petrobras. Finally, in 6.3 I present the similarities and variations in the abovementioned constructs by comparing both projects, breaking down the analysis to the level of each projects' phase.

6.1 Project Alpha

6.1.1 Capability Accumulation Process

Following a worldwide phenomenon, in which blockchain technology became widely known to the general public after the great appreciation of Bitcoin prices, occurred in 2017, Petrobras began foster experiences with this technology. The company was also engaged in several initiatives related to the technologies of the so-called industrial revolution 4.0, such as artificial intelligence, big data, cybersecurity, among others. At one point in time, as quoted by the project's technical leader, "Petrobras had projects in all technologies except blockchain". Feeling that they would be missing out if they ignore the technology, Petrobras' managers designated a team from CENPES (Petrobras' R&D department), which had the deliberated objective of experimenting with technology. The team had two major challenges: the first was to discover how technology works and how to implement it; the second was to know how the technology could be used to generate value for the company, that is, the team had to discover what were the most adherent business cases.

Petrobras partnered with a university which was already part of a larger program to foster joint research, called 'Connections to Innovation'. They settled a R&D project, with deep investigation over possible process which were simple to implement, and which had value to

the business. The University team counted with professionals, PhDs, MSc, and undergraduate students, employing multidisciplinary skills on the solution's ideation activities. In turn, Petrobras funded the initiative.

The team decided to focus on the procurement process, which is important for the company. Moreover, as a public company, Petrobras has specific bidding processes, which are more demanding in terms of disclosure, and may benefit from software-based improvements in general. They conducted several workshops to get a better understanding of the procurement process to identify a problem that could be solved by a blockchain-based solution. The solution was an application to record digital signatures of Petrobras contracts in a blockchain ledger. Their driver to pick this solution was that it should be "simple, but with potential to add value to Petrobras" (PUC-RIO, 2019). Moreover, they needed to decide what would be the implementation model (i.e., public network, BaaS, on-premises, or a new blockchain framework). The decision was partly based in a "feeling" from Petrobras' team that testing public network would be more challenging than with a private network. Therefore, they chose to create a protype in Ethereum Network.

The team selected to use a public blockchain framework (Ethereum) as the implementation model, which accelerated the prototype development, at least from a technical perspective. At first, Petrobras major concerns were mostly related to data security, such as not recording the text of a contract in a public ledger (only the hash was allowed to be recorded), for example. Apart from it, the project team leveraged upon using use an already available technology, a platform that offers a free of charges sandbox environment for the development of smart contracts, uses widely adopted programming languages, and requires no local infrastructure. Furthermore, as it is open-source, explicit knowledge is easier to acquire, through free documentation published on the community. Based on the Ethereum testing network, and in a simple infrastructure, significantly less demanding in terms of security when compared with Petrobras, the prototype is located at the basic capability level, as Figure 11 illustrates.

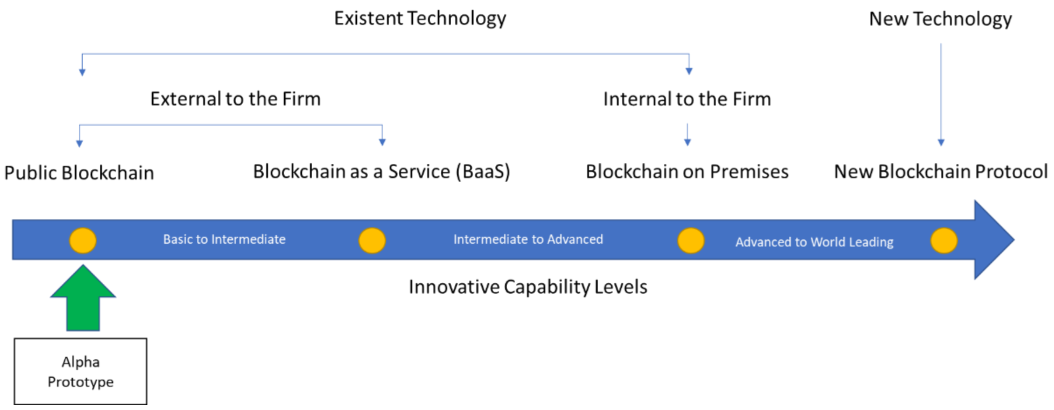

Figure 11: Innovative Capability Level in Alpha Prototyping Phase for Technical Dimension

Regarding the organization aspect, even though the company's procurement processes are affected by external stakeholders, such as suppliers and auditors, the blockchain solution was fairly designed to serve only to Petrobras' activities. Especially in prototyping phase, the project had little concerns with decentralization and joint governance, which simplified organizational discussions, limiting them to internal coordination only. It is important to notice that, even though the implementation model was based in a public blockchain (Ethereum), the application was contained in Petrobras organizational boundaries. That differentiation is critical for understanding some consequences of this new technology, as its use might be private, even though the technological artifact resides outside firms' technical environment. Figure 12 illustrates the organization capability level of Alpha prototyping phase.

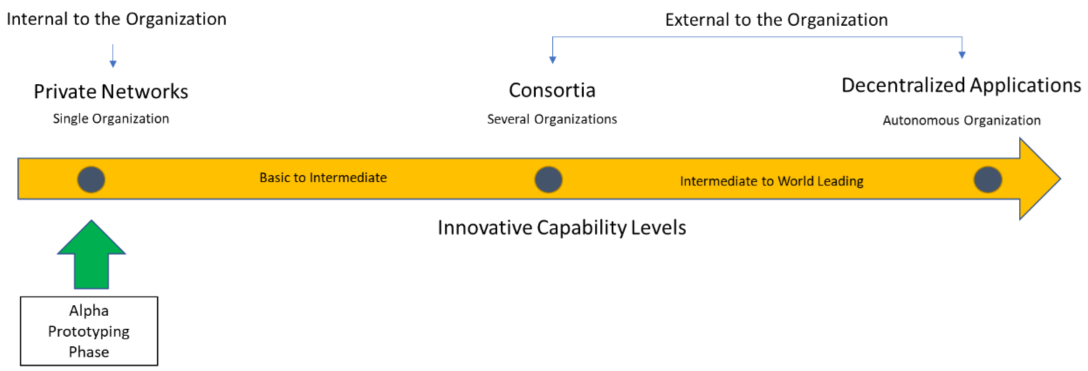

Figure 12: Innovative Capability Level in Alpha Prototyping Phase for Organizational Dimension

The development of the prototype took six months, and it took place in the university labs. Petrobras' multidisciplinary team worked on the project by setting their requirements, and validating the results, which should be compliant to the procurement process, cybersecurity standards and with law. This participation cannot be overlooked, because requirements were not clear upfront, and they needed to be adapted and refined as learning progressed.

After being validated, the prototype entered in a refinement phase, motivated by Petrobras' desire to internalize the artifact into their technical environment. Minor modifications were related to connectivity and security issues regarding existing protocols of communication between Petrobras' systems and other services through the internet. Notwithstanding, one major modification took place given the limitations of Ethereum's design for recording the public key of users. The original idea was to register the signature of Petrobras employees through using Ethereum's native feature of recording users' public keys, but this implementation required each user (i.e., each Petrobras' employee) to register on Ethereum network, which was not ideal. To overcome this undesired feature, the University team proposed an alternative solution to centralize records in an off-chain database to map internal users to signed documents, while using only one key to register transactions on Ethereum's ledger (Paskin, 2020). However, this solution reduces the blockchain to a secondary role, which is now a double-check mechanism for what is inside Petrobras centralized database. This means that instead of becoming the single source of the truth, it should rely on data located in another repository. On top of that, there is still an additional concern on the uncertainty about *gas* prices to use Ethereum's service, which are exposed to market fluctuations and may frustrate cost-benefit calculations. Such concern, however, was not tested in this phase, given that the solution remained in Ethereum testing network, in which tokens are free to use, and it was not promoted to Ethereum's Main Net (the 'production' network). Such adaptations reflect the project team's accumulation of innovative capabilities, as shown in Figure 13.

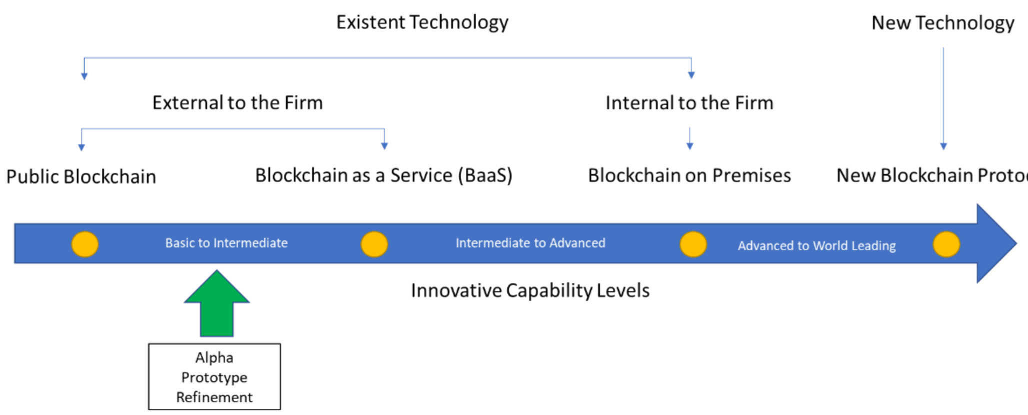

Figure 13: Innovative Capability Level in Alpha Product Development Phase for Technical Dimension

Although they can be analyzed separately, those dimensions are tightly linked. In this case, Ethereum's fixed design generated an organizational problem because it demands each employee to have an Ethereum digital wallet, with credits to pay for each transaction. Although it did not seem a showstopper, it changed the usual organizational dynamics to pay for services,

which are based in contractual procedures, where suppliers bill firms through a centralized process of acknowledge, acceptance and payment. Even in software-as-a-service cases, in which employees need to create an account on providers' websites, such as corporate electronic mailing services, the company is charged periodically (e.g., every month) for each registered account, and this procedure is well-known to every firm's financial department. What Ethereum offers is the opposite, no account is related to any entity, such as firms or governments, and every one of them must possess Ethereum's digital coin, individually. Moreover, there are no corporate charging processes, and even Ethereum is not a company, it is a decentralized community. Therefore, making this change is very costly to a large company, which would have to guarantee that every employee has enough tokens in their digital wallet before each transaction. Moreover, creating digital wallets may also be problematic, and the knowledge to do and use it is still not disseminated outside blockchain communities. Faced with this challenge, the team proposed no organizational change, deciding to adapt the technical solution to become more centralize, therefore not changing their capability levels in organization dimension.

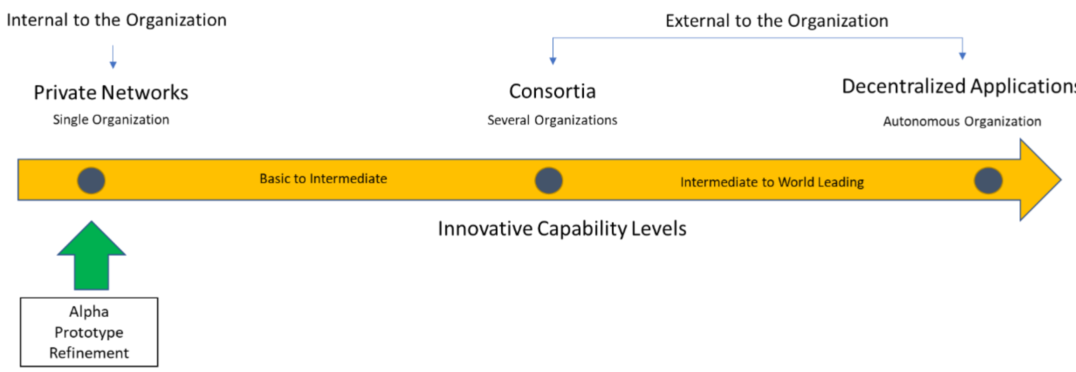

Figure 14: Innovative Capability Level in Alpha Prototype Refinement Phase for Organizational Dimension

At the end, the internalization phase lasted almost the same time as the prototyping phase. Several lessons were learned in the maturation process of the initial idea. Mainly, that the challenges to the adoption of a public blockchain network were understood more clearer, and despite its advantages, the team realized that using this model can still be quite complex. Moreover, it is important noting that these were lessons learned only after the experience, in arduous learn-by-doing dynamics, which was the Alpha's main objective in the first place. In fact, briefly after this project, Ethereum Foundation launched a permissioned version dedicated to firms, called Enterprise Ethereum, which addresses an important issue encountered by Alpha's team. Thus, there are indications that the team was facing a real issue in implementing Ethereum in corporations, rather than just a knowledge limitation.

6.1.2 The Role of Learning Efforts for Building Capabilities in Alpha

Existing capabilities: Petrobras' R&D department has been operating in cooperation with universities for decades and has a mature network of local cooperation (DANTAS AND BELL, 2011). Therefore, CENPES' developed capability to stablish alliances throughout several years made possible to identify and absorb external technological knowledge, accumulating it on top of existing internal knowledge base. More broadly, such cooperation initiatives are fostered through a large program called 'Connections to Innovation' (as described in section 3). Such examples are demonstrations advanced capabilities of CENPES' managerial systems for knowledge acquisition and generation through formal alliances with external knowledge sources. Moreover, as a R&D center, CENPES promotes the development of scientific knowledge through academic specialization and degrees, including IS technologies, enforcing employees' skills and knowledge base. Notwithstanding, CENPES employees are generally proud of its status as the largest R&D center in Latin America, and also of its contribution to Petrobras achievements at the innovation frontier in deep water upstream activities. CENPES managers also emphasize that R&D must generate return on investments through direct technological advance and by patenting and licensing. Therefore, such values and norms push CENPES employees towards knowledge acquisition of new technologies that might bring more clear results to Petrobras.

In a technical perspective, especially related to ICT-based innovation, Petrobras has advanced capabilities, such as world-class high-performance computing (as covered in section 2). Moreover, Petrobras has a large number of employees in Technology Information and Telecommunications department, and a large number of ICT suppliers, which constitute a strong knowledge base in several information technologies in their workforce, and in their technical systems. In terms of values and norms, IT department is historically focused on operational excellence, cost reduction and tight control of schedules in development projects. Furthermore, IT department's managerial systems regarding acquisition of external knowledge, favor partnerships with large technology suppliers to implement and support IT applications at lower costs and risks. Such strategy is directly influenced by the number of systems under the responsibility of IT department, and the size of Petrobras, with many departments attended by "central services", such as IT department operational support, for example. Additionally, as a state-owned company, Petrobras must follow rigid procurement processes, which are usually very time-consuming and impact managers strategic choices on procurement.

Other disciplines that were involved in Alpha project are related to Legal, Controlling and Procurement departments at Petrobras. In general, they focus on lower risk activities, especially due to transparency requirements of external entities over Petrobras. For example, Petrobras is audited by Federal authorities, tax auditors, Oil National Agency (ANP – Agência Nacional do Petróleo), and independent firms for Sarbanes-Oxley compliance. Therefore, in addition to operational excellence, such Departments are usually involved in innovation projects to secure Petrobras from non-compliant actions or security breaches.

External Knowledge Mechanisms Petrobras established a learning linkage with a local university in the form of a R&D project (as in Figure 4) to experiment with the technology and produce a functional prototype. In this prototyping phase, Petrobras team used this external knowledge to identify a suitable case to implement the technology. The University team counted with professionals, PhDs, MSc, and undergraduate students, employing multidisciplinary skills on the solution's ideation activities. In turn, Petrobras funded the initiative.

The university was also responsible for creating the prototype artifact to prove the concept. Such learning linkage proved to be pivotal in building initial blockchain capabilities for Petrobras, as commented by Alpha project leader:

> "[The project was created] to really test the technology because nobody had the knowledge, and nobody knew about the existing architecture standards, frameworks and programming languages."

In addition, the university transferred knowledge regarding smart contracts and public blockchain, through trainings and workshops. This knowledge was not only about the application they created, but it was also about the technology itself, including classes in programming smart contracts, and the general functioning, architecture, and cryptography Ethereum used. One member remarks that "even the legal team learned how to create a smart contract, which was very rich for them".

Furthermore, when Petrobras decided to internalize and refine the prototype, the learning linkage role was changed to technical assistance and provision (as in Figure 4). This change happened because both parts understood that there was no need for further effort in R&D activities outside what Petrobras internal teams were already undertaking, Notwithstanding, the university kept in contact with Petrobras team to provide diagnosis and formulation of solutions when issues arose.

Internal Knowledge Mechanisms: Although the established learning linkages was responsible for the bulk of knowledge implemented in Alpha prototype, Petrobras internal team acted proactively to disseminate an to create new knowledge. First, Petrobras knowledge integration was significant, as members of several departments, (e.g., Legal, Compliance, IT, Procurement) were assembled to the project team. This strategy proved to be very effective, as such multidisciplinary taskforce was able to accelerate knowledge creation and decision-making. In addition, the definition of requirements was more efficient, since there were multiple requisites from different areas in Petrobras, from the Procurement department (which would be the main user of the product), and IT Department' technical needs, to Legal and Compliance areas, concerned about the introduction of possible fragilities in Petrobras' processes. The project leader remembers:

> "We had Petrobras legal and compliance teams inside the project because we did not even know if we were allowed to use blockchain, given the many doubts about laws and regulations involving this technology."

Second, the creation of a second phase in the project, to internalize and refine the prototype was important to the creation of internal knowledge, as teams had to deal with many practical issues. Although the prototype was ready and validated, Petrobras' teams know that the complex technical and organizational environment of a large corporation imposes certain barriers to implement changes. Therefore, this second phase was a wise decision, as it was proven worthy, given issues that appeared in the internalization of the prototype.

Third, there were knowledge codification initiative in Petrobras' Legal team, through the creation of internal standards for evaluating future blockchain projects, in the lenses of legality, security, data privacy and contractual constrains. In fact, they used such standards in evaluating other blockchain projects that the company is currently undertaking.

Finally, the project team made exhibitions to other areas of the company, including a one-day event only about Blockchain, which was hosted in CENPES' facilities and presented speeches from external experts and Petrobras' managers and technicians, including Alpha's team. Such knowledge sharing events were mirrored in other areas, disseminating the possibilities of the technology, and the team was invited to help evaluating other ideas for blockchain applications.

6.1.3 Innovative Capabilities and Alpha's Outcomes

The prototype has been proved useful for Petrobras and enabled a series of internal and external demonstrations, which provided at least two qualitative benefits for the company. First,

it helped to disseminate internally the possibilities of the technology, which stemmed other initiatives. Second, it helped Petrobras to position itself as one of the first large companies to have a functional prototype among local firms. Thus, the successful prototype provided gains in social capital, strengthening the company's reputation as an innovative firm. Quoting a project member:

> “Nobody had a prototype at that time. We were hearing of many solutions, but we were not finding any prototypes, just ideas. Thus, it was important to show it around, to demystify blockchain and tell them that we did it. We were invited to show the prototype outside Petrobras, in BNDES and TCU [, which] asked us if we could give access for them to use. We asked to our managers, and we gave them the code, we open-sourced it to them.”

In practical terms, the main outcome of this project was a more refined prototype, which was adapted and improved. Although it was not implemented in production to this date, some research initiatives stemmed from Alpha, including participating in technical conferences (Paskin et al., 2020) and a rollout project for a process workflow tacking application. Moreover, mixed impressions from interviewees account for Alpha being a controversial blockchain use case, as digital signature providers are already available in the market. Using blockchain as a replacement for this more mature technology would only make sense if it removed costs or generated significant gains to the company, which did not seem to be the case yet.

Overall, Alpha is regarded as a successful R&D project since it met the desired outcomes, which were related to knowledge absorption and increasing internal awareness of blockchain possibilities. However, the prototype had not advanced to a product development stage, given cost-benefit considerations, especially when a more stablished technology is already available. Such limitation to reach a business outcome was a direct reflection of the little specific knowledge available at the beginning, when the prototype was designed. Notwithstanding, the same existing capabilities that constrained the results in Alpha, are now increased with lessons learned in this project. One direct output was the current enhanced skills to evaluate new blockchain ideas from technical, legal, and business points of view.

6.2 Project Beta

6.2.1 Capability Accumulation Process

The main motivation for Project Beta is linked to an institutional crisis that occurred because of corruption investigations of Petrobras top managers, which was held between 2014 and 2019, in the context of ‘Lava Jato’ Operations. These actions caused economic damage to shareholders, including Brazilian population, and strongly damaged the company's image. Faced with an external shock (KIM, 1997), managers responded by strongly focusing on

corporate governance and controlling. In this case, their main objectives were reducing compliance risks and increasing transparency. Moreover, it was in line with a major ESG program to enhance compliance and regain the trust of investors and the society.

In a broader sense, such goals were in line with the key benefits touted by blockchain experts, and a favorable business case came from an employee in the finance department who aimed at the existent process of granting powers of attorney for bank accounts to employees. The process was entirely manual, paper-based and involved multiple actors, such as the Petrobras' finance department, notary offices and banks' back-office departments. As a result, there was an opportunity for digitalization and tackling information asymmetry, saving time and resources. Moreover, cryptography combined with digital signature of documents could provide security and significantly improve the existent movement of paper documents between different companies. Additionally, the solution was designed to be scalable and work in a network of multiple companies, notary offices and banking institutions, creating standards for the market, and enabling the sharing of maintenance costs. Therefore, such detailed business case indicated that there was a knowledge base in the Finance team, in such level that they could identify opportunities and propose high-level solutions, taking advantage of some unique features, such as a decentralized and distributed ledger, to accelerate the process and reduce risks simultaneously.

After maturing the business case and getting internal approval, Finance team searched for a Bank to establish a partnership. In that pursue, Petrobras counted on its well-developed capability in managing innovation partnerships with its suppliers (DANTAS AND BELL, 2011). However, they were not being successful. As some interviewees highlight, it was only after that the project came to the attention of the then Petrobras CFO that the difficulties to find a partnership were removed. As Granovetter (1985) notes, the economic activity is embedded in social connections. In this case, the team was benefited by the fact that the then Petrobras CFO was the former President of the Bank, which happens to be also a long-time partner of Petrobras. In fact, some interviewees said that it was crucial to the project and opened many doors because it created engagement in both firms for this initiative.

The prototype was developed using the Hyperledger Fabric permissioned framework, and it was relatively easy to set up, given the financial institution's existing capability acquired in a previous project. Moreover, the bank had already a technology partner and a service contract to use IBM Blockchain Platform, which is one of the main BaaS available in the market

(Figure 15). The bulk of teams' efforts were related to understanding the process, designing the solution, programming the solution, and testing it.

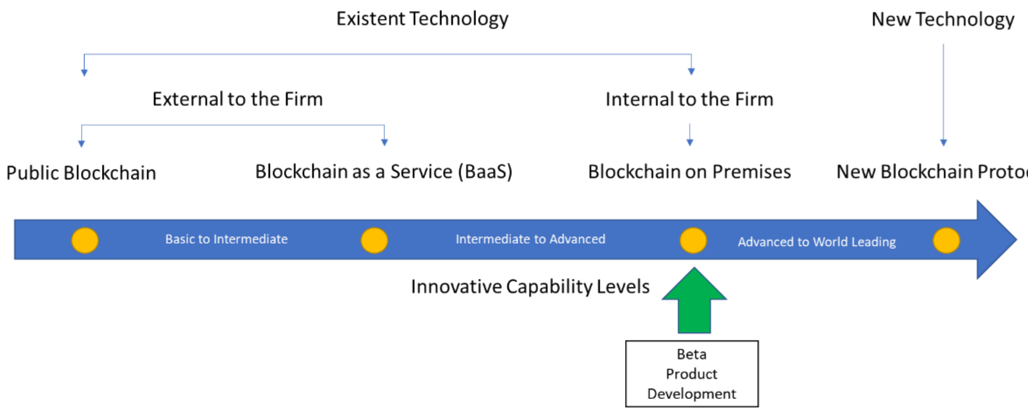

Figure 15: Innovative Capability Level in Beta Prototyping Phase for Technical Dimension

Regarding organizational dimension, the original intent of Beta was to serve as a network for banks and its clients, simplifying back-office processes to grant power of attorney in bank accounts to employees of the firm. Given that all these requests and signatures are validated by notary offices today, there is also an opportunity to reduce costs by removing or, at least, changing the role of this intermediary. Moreover, the intent is to create a network with major players in the country to share the costs of maintenance, reduce paperwork and improve process standardization. Such goals request an intensive orchestration between all actors (banks, client firms, and possibly the notary offices) and a very effective governance system, which would drive the implementation through the creation of a consortium. However, in this first phase, both Petrobras and the bank opted to develop the prototype to reflect the current process that governed their own interactions. Therefore, they postponed larger discussions over governance and standardization to another phase. Figure 16 illustrates the basic-to-intermediate level in organizational dimension.

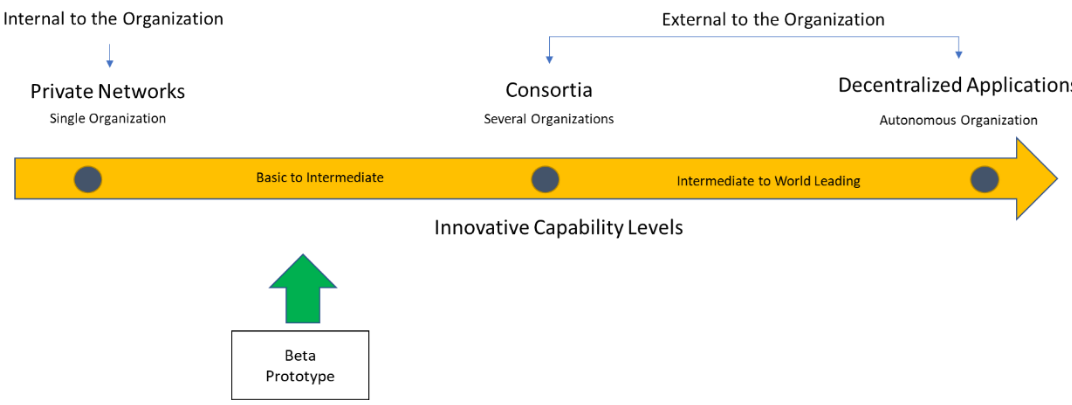

Figure 16: Innovative Capability Level in Beta Prototyping Phase for Organizational Dimension

After the prototype was approved by both sides, a product development phase followed. This phase had the objective to evolve the artifact into a functional product, available in a production environment, enabling Petrobras and the Bank to automatize the interorganizational process of granting power of attorney, and to scale the network for several companies and banks. However, there was great debate over whether Petrobras should continue with this prototype, instead of promoting the creation of a network of banks that could provide the services to the clients (Petrobras included). Some argued the prototype had already served to prove the concept, and the partner bank could join with others to build a network and provide this service. Proponents of this approach emphasized that the product was essentially a banking service, and that Petrobras could help promoting the product, but would not have a return proportional to its investments. However, general impressions account for a low maturity level to decide what were the best technological and business approaches.

The product development phase was the most challenging in technical terms. In order to implement a on-premises model, the team had to recur to open-source documentation mostly. Furthermore, it was necessary to involve other teams such as those in charge of databases, networks, cyber security, front-end, *et cetera*. Much of what these teams needed to implement was not in previous stages, which started an intense trial and error, learning by doing, development at Petrobras. The team had difficulties to implement Hyperledger Fabric and orchestrate its components, mainly Kafka/ZooKeeper, which took weeks of work as the team had no expertise with such software. Not coincidentally, the Hyperledger documentation report many users facing issues with these components, and that deploying them can be “tricky, requiring a high level of expertise in Kafka infrastructure and settings” (HYPERLEDGER, 2021) In addition, when the project started, Hyperledger Fabric version 1.0 was the only available, it was based on a specific architecture and using a set of components, which were discontinued or deprecated in Fabric version 2.0 (Kafka and Composer included). Such

experiences reveal how the technology was still in their first steps, with many technical challenges even in the more mature frameworks. Moreover, high levels of expertise were required in different technologies and standards (e.g., Kubernetes, ordering services, chaincodes, security models) just to implement the Hyperledger Fabric framework on-premises. Figure 17 illustrates the higher technical capability levels in place.

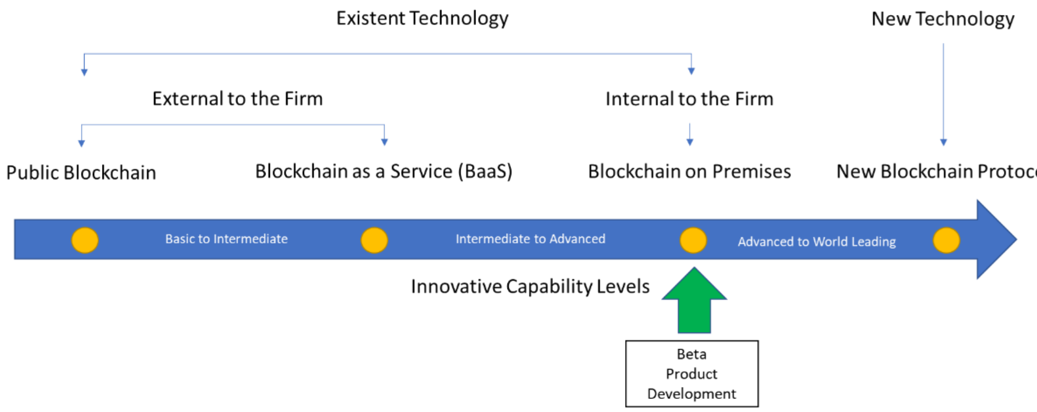

Figure 17: Innovative Capability Level in Beta Product Development Phase for Technical Dimension

During product development phase, Petrobras and the Bank had to design and implement a governance to the newborn consortium. The first step was to create a shared intellectual property registry, which was relatively simple given the high capacity in the companies' legal sectors. Next, they needed to set up technical and business rules, and procedures for the maintenance of the blockchain network and evolution of the solution. At this point, the teams had great difficulties in finding examples of such device, not only in Portuguese, but also one adherent to the Brazilian legislation, which ended being developed by Petrobras' team, after adapting a Hyperledger standard document, suggested by Petrobras' architect and validated by their legal team. In addition, product requirements were monitored through a technical committee, which had the responsibility for prioritizing, testing, and accepting the features. Although relatively tied to this committee regarding blockchain network and smart contracts, each company acted independently in their own systems off-chain. Figure 18 illustrates the advance in organizational dimension given the more advanced themes and artifacts that were developed.

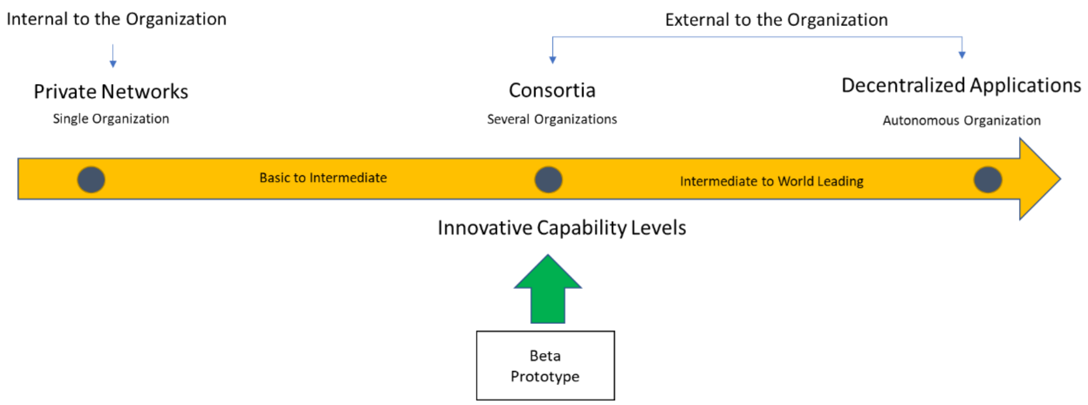

Figure 18: Innovative Capability Level in Beta Product Development Phase for Organizational Dimension

6.2.2 The Role of Learning Efforts for Building Capabilities in Beta

Existent Capabilities: In managerial systems dimension, Petrobras Finance team has a close relationship with their suppliers of banking services. In special, Brazilian banking sector is very concentrated, with a handful of big players dominating the market. Consequently, relationship with banks is quite steady, with Petrobras managers having constant contact with banks commercial representatives, which strongly favors contribution between them. Moreover, Petrobras exchange high volumes of data with banks in a daily basis through their technical systems, with special concentration in back-office activities such as payments and receivables. Such processes have already been the target of a significant project, with Petrobras' Finance team coordinating efforts for standardization and automation of bank reconciliation processes, stablishing communication between Petrobras' ERP and its partners' systems. Such employee knowledge base, acquired from previous experience with implementing an interorganizational systems added a lot to the Beta project, as there were similarities between both initiatives.

In a technical perspective, although not mastering blockchain technology, Petrobras had a capable team of cybersecurity, networks, and container-orchestration technologies, which were all requested to implemented on premises blockchain networks, such as Hyperledger Fabric. Such existing knowledge embedded in employees and technical systems facilitated internal knowledge creation and external knowledge identification and absorption. In special, in internal knowledge integration mechanisms, the plurality of technologies mastered by Petrobras' IT professionals were pivotal in implementation of a on-premises model. Although they faced difficulties, an acceleration was clearly observed when issues were limited to one

technology that Petrobras' team had already a previous knowledge base. Most critical issues were at the interface between such technologies with blockchain specific components.

External Knowledge Mechanisms: Petrobras found a partner that combined the advantages of being open to a co-innovation initiative and having already some experience with blockchain. Thus, the project would be carried out in partnership between the client company, owner of the initial idea (i.e., Petrobras) and the supplier bank, interested in possible disruptions in the specific service, and experienced in the technology, serving as a source of knowledge and an investor.

The learning linkage established between Petrobras and the Bank took the form of a R&D project, which started with a prototyping phase. For three months, employees from Petrobras' IT and Finance departments frequently visited the bank's Innovation Lab, where they exchanged experiences, learned the technology, and built (hands-on) the prototype's smart contracts, while other parts of the application where develop in-house. While developers from both Petrobras and the Bank IT departments exchanged knowledge and worked together, members of both Finance teams were giving the business and functional requirements that guided the prototype. Petrobras' teams reported acquiring great learning experiencing the bank's innovation environment, both in the application of the lean practices in the prototype development process, and in the ease of technological experimentation of the innovation labs. Both organizational structures acted as facilitators to innovation and were not available for Petrobras professionals in their departments at the time, which only happened after a major digital transformation program at the company.

Such learning activities were decisive in the qualification of Petrobras employees and had direct effect in capability accumulation. First, Petrobras developers were responsible for creating and testing the smart contracts, and the Finance team influenced directly in prototype's requirement, together with Bank's business team. Both Petrobras' IT and Finance teams were only able to do it because the skills acquired in the period when they stood in Bank's innovation labs. Second, all infrastructure and blockchain network configurations were done by leveraging on Bank's BaaS agreements with IBM, which were done before Beta's project, therefore taking advantage of Bank's existing capabilities to undertake joint R&D projects with blockchain. Moreover, as the Bank had already initiated a path with Hyperledger Fabric, all knowledge that Petrobras team absorbed was limited to this framework.

In Beta's product development phase, there is a sensible change in how Bank's capabilities could help Petrobras Hyperledger implementation. First, because Petrobras' teams were not yet fully prepared to absorb the prototype in their environment, nor developing the product on their own. As such, Petrobras' IT team had difficulties to decide over the best implementation model. At this point, there were basically two options: absorbing the entire infrastructure, creating servers dedicated to the application and setting up a node in a Hyperledger network, or hiring a Blockchain-as-a-service provider (BaaS), just uploading the codes, and connecting to the network channel. Both options had pros and cons, such as the possibility of expanding the technical team's knowledge of the Hyperledger technology, but with a much greater effort of assimilation, if they opted to go for their own infrastructure; or saving time and resources in technical implementation, but at the cost of searching and hiring a BaaS provider, which they did not master at that time. It is important to notice that, from both options, the bank would be more capable to advise about BaaS, since they have chosen this model in their blockchain operations. After pondering the question, Petrobras' team opted to implement an on-premises model, not recognizing at the time the limitations of the bank to provide this specific knowledge.

Second, in the product development phase, discussions over the governance of the network began. Governance rules are required for formal and contractual reasons, mainly regarding responsibilities for network maintenance, cost structures and collecting procedures, and agreements over the way the requirements of the distributed application will evolve, including changes in the ledger's configurations. Notwithstanding, the Bank had no previous experience with this kind of organizational arrangement, at least regarding governance of blockchain networks.

Consequently, Petrobras learning linkage with the Bank could not provide external knowledge to support both the chosen implementation model, more demanding when compared with Public Networks and BaaS models, and the coordination levels, necessary to create and mature the consortium governance, was significant to postponing the outcomes and reducing the benefits. Such technical and organizational knowledge gaps, specific to blockchain, affected the capability accumulation process, in more than one way, as Petrobras had more difficulties to overcome emergent issues, incurring in delays, halts and increasing resistance to keep funding the initiative.

To surpass such challenges, Petrobras team had to access other external sources, mainly codified knowledge available in Hyperledger community forums, and open-source

documentation. Additionally, some informal linkages were stablished with experts that were contacted by Petrobras team members in their participation in blockchain related events. Furthermore, as Petrobras is also a client from IBM (which is one of the major companies in Hyperledger initiative, and provides services on top of Hyperledger framework), the team arranged some informal meetings with Hyperledger community leaders in Brazil, including one senior Hyperledger architect. Only after significant effort to master the technology through internalizing explicit knowledge that Petrobras could finish the technical implementation.

On the organizational aspect, the main artifact was the governance document, which was only created after a Petrobras architect managed to find a standard document for consortia in Hyperledger community, translate it to Portuguese and interact with Petrobras' Legal team to evolve the subject and forge its final version.

Virtually all interviewees proudly highlight that this project was jointly undertaken by both companies, without significant participation of a third party, whether a consultancy or a technology supplier. Although it was a strong indication of the increased capabilities, much effort would possibly be saved if some more knowledge-intensive learning linkages could be established with specialists in the specific technical and organizational issues reported here. In addition, Petrobras' technical team also emphasized that they did not receive any training from technology suppliers, limiting their learning to the experiences reported in the Bank's innovation lab, open-source documentation, forum discussions in Hyperledger forums, and to internal activities, such as knowledge transferring from original team members to those who joined the project after.

Internal Knowledge Mechanisms: Internal knowledge mechanisms were more substantial in two times. First, this project was part of a larger program to automatize and enhance controlling capabilities in Petrobras Finance department's activities. Several processes and technological solutions were studied previously by Petrobras' employees and consultants to evaluate the projects' economic and technical feasibility. Therefore, Petrobras' internal knowledge sources were activated to create new knowledge before the project even started. In the case of Beta, the Finance Manager said:

> "We had many technological projects addressing improvements in some of our activities. However, we had concerns over the process for granting power of attorney to bank accounts that we could not find a solution, until one of our consultants made some research and came up with the idea of using blockchain".

Second, in product development phase, internal learning mechanisms were promoted, much as in response to the difficulties in obtaining external knowledge, in interpreting and

internalizing codified knowledge, or because high turnover in the project team. Overall, the project had several halts and had difficulties to keep on planned schedule. The two-years long development period was caused by delays in decision making on both sides, resulting in several interruptions and restarts. Consequently, turnovers and relocations were substantive, and teams had to engage in knowledge sharing activities to mitigate discontinuities. In fact, the problem was so intense that no developer who had participated in the prototyping phase was on the team at the end of the product development. Knowledge codification had also taken place as architecture and cybersecurity internal standards were created to guide future implementations. Moreover, codified knowledge in the form of specifications were instrumental to preserve the knowledge between project interruptions and restarts. Such electronic repositories were then accessed, the codified knowledge was retrieved and re-socialized afterwards.

Other internal knowledge sharing activities took the form of internal forums and conferences. Moreover, many managers associated blockchain with Bitcoin, and were mistakenly surprised by the idea that Petrobras was using Bitcoin in association with a bank. Thus, such managers had little skills to make decisions over this more sophisticated smart contracts-based solution, which was an additional obstacle. Therefore, the exhibition of the prototype in internal events was important to demystify the technology and align the knowledge to a required level to enable such decision-makers.

6.2.3 Innovative Capabilities and Beta’s Outcomes

At the end of the product development phase, the team was able to produce a functional product, which linked the process workflow in both companies. However, several initial objectives were not fully achieved. First, the product did not have all the functionalities needed, which affected its adoption and is used only marginally today. Second, some design decisions made were not entirely clear to both parties, and the smart contracts do not reflect the standard process, still needing adjustments. Third, the product design led to a large overfitting to both companies' processes, and it is not scalable yet to the idealized model of multiple companies and financial institutions.

It is important noticing that such results were constrained by Petrobras’ existing non-blockchain-specific capabilities. Moreover, Petrobras learning linkages affected the outcomes differently, when comparing both phases. In prototyping phase, when the infrastructure was based in the bank existing configuration and specific blockchain organizational arrangements were not necessary, the learning linkage was very prolific and heavily based in external sources (e.g., the Bank). Moreover, Petrobras team absorbed the knowledge that they were exposed and

experienced. However, such experience was limited to smart contracts and general configurations of Hyperledger Fabric framework, which was proved insufficient to implement the network in Petrobras infrastructure, and it was due to the difficulties that Petrobras had to identify that the required knowledge could not be fully acquired from the same external source. Therefore, blockchain's technical dimension affects the choice of learning linkages which can provide (or not) the external knowledge to undertake innovative projects.

Although not reaching the desired business results yet, Petrobras managed to accumulate intermediary and advanced levels of capability to finish the product development, establish inter-organizational governance and launch the application in productive environment, which is one of the first blockchain cases in Brazil. However, such feat was only possible due to continued learning efforts, and extensive actions from project sponsors, who protected it from cancelling, despite several interruptions. Moreover, the installed infrastructure is an organizational asset by itself, as it can be used to several other blockchain initiatives on top of permissioned Hyperledger Fabric framework. In fact, it is still in use as both companies are still committed with the project, and a new iteration has started to overcome the limitations mentioned. They are having discussions to invite other companies to join in, including notary offices which can improve the process in their vision, in a clear demonstration of capability accumulation.

6.3 Comparative Analysis

Both cases indicate that Petrobras' existing non-blockchain capabilities had mixed effects on learning efforts, acting as accelerators in some functions and as obstacles in others. Moreover, there were variations in how such capabilities were in use given the different areas of Petrobras that took part of Alpha and Beta projects. Although Petrobras did not have any blockchain-specific capabilities accumulated previously from Alpha and Beta projects, non-blockchain-specific capabilities had influence on acquiring external knowledge through advanced capabilities in alliance-making with suppliers and universities. Moreover, technical learning was accelerated due to existent ICT-related capabilities, such as a large number of employees in R&D and in Information Technology and Telecommunications departments (including personnel with PhD and MSc degrees and professional certifications), large contracts with technology suppliers, technical domain in multiple technologies and an installed ICT infrastructure. Especially in Beta, in which Petrobras advanced to deeper capability levels, the previous experiences in collaborating with Banks and the availability of a technical infrastructure to absorb a on-premises implementation model were pivotal.

On the other hand, impediments derived from existent capabilities (LEONARD-BARTON, 1992) had impacts on knowledge acquisition and on the business outcomes of Alpha and Beta. For example, IT Department's focus on lower risk projects had created tension between Finance and IT teams. According to the Finance manager involved in the Beta, IT managers resisted to mobilize teams because they did not see blockchain as mature enough to invest, and they also resisted to send professional to the Bank's Lab. Moreover, experimentations were frequently cited as much easier outside Petrobras technological infrastructure, when compared with experiences in Innovation Labs in both cases, whether it was in the University or in the Bank.

Additionally, as IT procurement strategy focused on large, stable and lower risk contracts with major players, they could not stablish learning linkages directly with technology providers fast enough. In fact, external knowledge came from alliances stablished by R&D and Finance teams in Alpha and Beta, respectively. While, in Alpha, such learning linkages proved sufficient to achieve its goals, the knowledge gap created in Beta by Petrobras adopting a different implementation model from the Bank, could not be filled by a technology partner, or even by formal training, which forced Beta's team to search for open-source knowledge and informal learning linkages. Moreover, even the decision to go for an on-premises model was directly affected by difficulties to stablish formal contracts with BaaS providers.

Some impediments also limited innovative capability accumulation to intermediary levels, especially in blockchain organizational dimension. For example, Petrobras managerial systems and norms highly focus lower risk, clearer return over investments and the needs to comply with heavy regulations might constrained Petrobras' options for applications in lower risk processes, such as back-office tasks. Moreover, as blockchain more advanced decentralization cases have still challenges with existent legal frameworks, it was unlikely that Petrobras teams would adventure in such projects, given the company's strong focus on legality and compliance.

The role of learning linkages as external learning mechanisms was important in creating the first Petrobras' blockchain innovative capabilities. However, as the activities were progressing in both projects, the learning linkages had different impacts. While in Alpha, there university acted as a catalyst to Petrobras experimentations with blockchain from the beginning to the end of both phases, in Beta, the Bank's contributions were very high at the beginning, but diminished as the project progressed. The major difference was that the university, to say the least, had sufficient capabilities to meet the lower levels of technical and organizational

blockchain dimensions, and those dimensions did not change significantly between the prototyping and the prototype refinement phases. On the other hand, the Bank had sufficient technical capabilities to meet intermediate levels, given they had already previous experience on top of a BaaS platform, and basic-to-intermediate organizational levels, given that they had no previous experience in consortia governance. Notwithstanding, these capability levels were adequate for the prototyping phase, however Petrobras and the Bank had to accumulate knowledge to meet the more advanced capability levels in the product development phase. Moreover, they need not to meet the same levels in both dimensions, given the fact that the Bank could use their technical environment with minor adaptations, as their BaaS-based model was capable to provide the connect with the Hyperledger Fabric channel created for Beta. The same was not true for Petrobras, especially because they decided to go for a more demanding implementation model. Finally, both partners had to improve their blockchain specific organizational dimension capabilities to establish routines and agreements for governing the consortium. Figure 19 illustrates the findings regarding the progress of capability levels in each projects' phases.

Regarding the internal learning mechanisms, they were more intense in Beta project, given the search and experimentation undertaken before the project started, as a preparation for building the business case and defending it in requests for budget. After both projects started, such mechanisms became similar, as Petrobras joined multidisciplinary teams for each initiative to create knowledge integration, accelerating learning and problem-solving activities. While in Alpha it was especially important for guaranteeing compliance with internal norms and legal constraints, which required active participation of internal auditors and legal department professionals, in Beta it was mainly focused on technical ICT-related issues stemmed from multiples components and different technologies (e.g., cybersecurity, cloud infrastructure, Kubernetes). If were not from effective internal knowledge integration, such progress would be hardly achieved, as one team could not absorb knowledge from so many different fields.

It is important noting that, despite being analyzed separately, both Alpha and Beta projects occurred roughly on the same period, and although they were not synchronized or coordinated efforts, they had some influence on each other. For example, one factor for Alpha team to decide between public and permissioned blockchain frameworks was that they had some information on Beta initiative on top of a permissioned framework. On the other hand, Beta team attended to events dedicated to blockchain technology promoted on CENPES, in which Alpha team had a speech. Moreover, Beta team had request at least two meetings with

Alpha team to collect lessons learned, however the projects' scopes were very different, which are also represented in technical and organizational dimensions of each one. Therefore, not only both teams shared their knowledge to other areas of Petrobras, but they also did it between them. Furthermore, knowledge codification was also important to the project results and to Petrobras body of knowledge, which was used for evaluating other blockchain business cases. In the case of Beta, it was important to support teams after reallocations and turnovers during the project.

Regarding the implemented blockchain activities, Alpha and Beta differ mainly because the latter became a product, while the former remained at prototyping phases. Consequently, process adaptations to adopt the solution and to support its functioning where undertaken. Moreover, governance structures were developed to support and evolve the solution, including preparing it to scale up for other firms and banks.

Both projects generated business outcomes in the form of technological assets, by increasing know-how in public and private blockchain networks, and in implementation models. Additionally, the major technological output of Beta was the creation of a Hyperledger network and infrastructure, which now allows Petrobras to join or create other networks with minimum efforts. Furthermore, given the achievements in creating blockchain prototypes and product, Petrobras has also obtained outcomes in their Reputational assets, as it reinforced its image of an innovator organization, especially in Brazilian market.

Finally, Beta can be considered a structural asset, as it created a governance structure between Petrobras and the Bank, which now rules over an interorganizational processes, and provides the foundations for potential collaborations with a network of other firms in a multitude of interorganizational processes. Table 6 offers a consolidation over the findings described above.

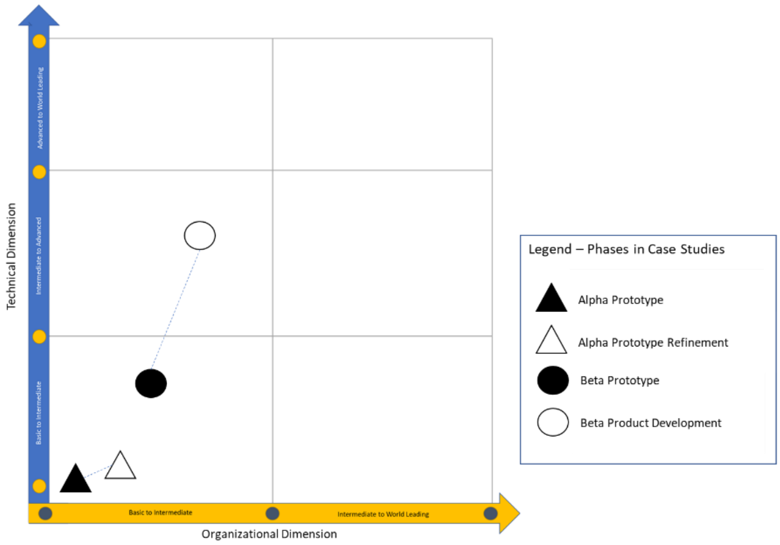

Figure 19: Petrobras' capability accumulation as described in cases

Table 6: Summary of findings

Project	Existing Capabilities	Business Outcomes	Phase	Internal Learning Mechanisms	External Learning Mechanisms	Blockchain Dimensions Capability-Accumulation
Alpha	**Accelerators:** Employee knowledge base: large number of employees specialized in various IS technologies in IT Department; large number of employees with academic degree and technical specialization in CENPES. Technical systems: Capable technological infrastructure. Managerial systems: CENPES' developed capability to stablish alliances with universities; several contracts with major ICT suppliers. Values and norms: CENPES' focus on acquiring and creating knowledge to Petrobras activities. **Impediments:** Technical systems: Focus on operational excellence difficult experimentations and creation of sandbox systems. Managerial systems: Heavy legal and compliance controls over Petrobras operations. Values and norms: Emphasis on returns over investments in R&D projects drives prioritization of short-term and lower risk investments.	**Technological outcomes:** increasing know-how in public blockchain networks and in implementation of Ethereum smart contracts; creation of internal legal and IT standards; prototype is being used in spin-off projects. **Reputational outcomes:** reinforced image of an innovator organization, due to early production of a functional prototype in Brazilian market.	Prototyping	Knowledge Integration Knowledge Sharing Knowledge Codification	Learning Linkages with University in the forms of R&D project and R&D training	**Technical**: Basic prototype of smart contracts at Ethereum Public Blockchain, without communicating with Petrobras internal systems. **Organizational**: Basic application for Petrobras' internal use only.
			Prototype Refinement	Knowledge Integration Knowledge Sharing Knowledge Codification	Learning Linkages with University in the form of technical assistance	**Technical**: Basic prototype of smart contracts at Ethereum Public Blockchain, with adaptations to communicate Petrobras internal systems and centralize Ethereum accounts. **Organizational**: Basic application for Petrobras' internal use only.

Project	Existing Capabilities	Business Outcomes	Phase	Internal Learning Mechanisms	External Learning Mechanisms	Blockchain Dimensions Capability-Accumulation
Beta	**Accelerators:** Employee knowledge base: Finance and IT Departments' previous experience with implementing an interorganizational system added a lot to the Beta project, as there were similarities between both initiatives; Capable team in a plurality of technologies (e.g., cybersecurity, networks, container-orchestration), which were all requested to implement on premises blockchain. Technical systems: Capable technological infrastructure. Managerial systems: Finance Department's developed capability to stablish alliances with their suppliers of banking services; multiple contracts of IT suppliers. **Impediments:** Managerial systems: Procurement processes and strategies difficult stablishing formal alliances with blockchain external knowledge sources through training and technological guidance. Such difficulties to stablish partnerships, also affected implementation choices, creating a gap between Petrobras' and the Banks' implementation models. Values and norms: High project management discipline on costs and schedules difficult resource allocation in more uncertain initiatives.	**Technological outcomes:** increasing know-how in permissioned blockchain networks and in implementation of Hyperledger smart contracts; creation of internal IT standards; creation of a Hyperledger network and infrastructure, which now allows Petrobras to join or create other networks with minimum efforts. **Reputational outcomes:** reinforced image of an innovator organization, due to early production of a functional prototype in Brazilian market. **Structural outcomes:** blockchain governance structure between Petrobras and the Bank, scalable to other companies and other application and processes; automation and standardization of interorganizational processes.	Prototyping	Training & Experimentation Knowledge Sharing Knowledge Integration Knowledge Codification	Learning linkage in the form of a R&D project	**Technical**: Intermediate prototype level, in a Hyperledger Fabric BaaS platform, without communicating with Petrobras internal systems. **Organizational**: Basic Dyadic semi-informal relationship, without governance rules or cooperation terms.
			Product Development	Knowledge Integration Knowledge Sharing Knowledge Codification	Learning linkage in the form of a R&D project. Knowledge Acquisitions od codified tests through Hyperledger Documentation and Hyperledger communities. Informal learning linkages with experts in external and internal conferences	**Technical**: Advanced product level, in a Hyperledger Fabric on-premises infrastructure, communicating with internal ERP system and compliant with cybersecurity internal requirements. **Organizational**: Intermediate Dyadic formal relationship, with governance rules, cooperation terms and shared process in a blockchain ledger.

7. DISCUSSIONS, IMPLICATIONS AND CONCLUSION

Firms are still experimenting with blockchain technology, trying to discover where it can be used to improve their processes and generating innovative products. However, the fact that the technology is still maturing and all the hype surrounding it often blurs the understanding of its real possibilities today and in near future. Moreover, firms engaging in blockchain initiatives often do not know where to start because they did not develop blockchain-specific capabilities. This study explored how Petrobras created its initial blockchain specific capabilities by focusing on its first projects in this technology. In addition, it provided more detailed understanding of how blockchain technical and organizational dimensions affect the required intensity in learning efforts, the capability accumulation process, and the outcomes of innovation activities, represented here by the blockchain projects and their phases. Furthermore, this research shows how existing non-blockchain-specific capabilities adds to learning mechanisms, in a representation of Petrobras' total learning efforts.

7.1 Discussion of Findings

In relation to the first research question, on what capabilities were accumulated by Petrobras through their innovation projects, it was found there were differences between projects Alpha and Beta relative to the accumulation of capabilities.

In Alpha, the prototype created in Ethereum Public Blockchain, reached basic technical levels, as it uses a 'out-of-the-box' platform, which can be programmed to attend specific needs (trough smart contracts), but does not allow major adaptations in its features. In fact, such characteristic imposed a limitation to its use, which had to be completed by an internal workaround solution in a subsequent phase. This minor improvement indicated a minor capability accumulation within the same project team. In the organizational dimension, the project remained at a basic level, given that its use was limited to a single organization. As illustrated in Figure 19, there were variations in team-level capabilities between each phase in Alpha regarding the technical dimension.

In the case of Beta, the prototype was produced in a Hyperledger Fabric framework, on top of a BaaS platform using the Bank infrastructure, without communicating with Petrobras' systems or network. Therefore, Petrobras had accumulated intermediate levels in technical dimension, while it reached basic level in

organizational dimension, given the simple dyadic, and semi-informal agreement, without governance rules or cooperation terms. After the prototype was approved and a product development phase initiated, Petrobras decided to internalize the technology in a on-premises implementation model. Such decision heavily affected the capability accumulation, as Petrobras moved away from the model the Bank has used in the prototyping phase, which initiated intense leaning efforts to identify complementary external sources and create knowledge internally, in order to fill emergent knowledge gaps, ultimately leading Petrobras to advanced blockchain-specific capability levels in technical dimension. Notwithstanding, the more robust governance rules required for operating the consortium also demanded learning efforts to complement knowledge, leading to an advance in capability levels to intermediate levels in the organizational dimension. Therefore, variations observed in capability-accumulation and the intensity of learning efforts within Beta were explained by different technological and organizational requirements, which in turn, were created by Petrobras managers' decisions to move away from the implementation model in place at the Bank.

In relation to the second question, on how Petrobras has accumulated their blockchain-specific capabilities, this study explored the learning effort to explain the variations between both projects and within each project's phases. The findings indicate that capability-accumulation was directly affected by variations in learning mechanisms and in how non-blockchain-specific capabilities act as facilitators or impediments to knowledge generation.

In the case of Alpha, external learning mechanisms corresponded with the largest part of the learning mechanisms, adding technical expertise, helping Petrobras to define the problem, and developing the solution. Such collaboration took the form of a R&D project (Figure 2) in the prototyping phase, changing to technical assistance in the prototype refinement phase, assisting Petrobras on stand-alone requests, solving problems, and clarifying doubts. Notwithstanding, Petrobras' internal efforts in mobilization of a multidisciplinary team, and in creating internal events dedicated to blockchain facilitated access to a broader internal knowledge base and accelerated the crystallization of external knowledge. Moreover, codification activities took the form of internal standards in legal and IT departments (Table 6). Such activities represent the spiral of knowledge (NONAKA AND TAKEUCHI, 1995), in which knowledge is transferred and created through socialization, interpretation and codification dynamics.

In the case of Beta, internal knowledge efforts were more prominent, as a reflection from more demanding technical and organizational requirements, especially in product development phase (as described in 6.2).

However, one might argue that the achieved blockchain-specific capabilities depend first on the intended innovation activity to be measured, as one can only observe the level of expertise through innovation outputs. Thus, if a project has more modest objectives to accomplish than another, then variation was not inserted because divergent learning mechanisms, but it was endogenous to the innovation activity. However, the findings indicate that such alternative explanation is not applicable. For example, Alpha's initial objective was only experimenting with blockchain through R&D efforts with a university, to provide the absorption of external knowledge. Moreover, there were no previous efforts, internal or external to define the project's scope. In fact, the university and Petrobras teams followed a driver to maintain low levels of complexity in the prototyped solution, which limited the project scope. On the other hand, in Beta there was a business intent to use the technology, addressing an existing problem. Petrobras' Finance team only came to blockchain after undertaking an in-house initiative, in a deliberate learning effort (ZOLLO AND WINTER, 2002). Therefore, Beta's scope was the direct reflection of internal learning mechanism before it has started, given lessons learned from internal search (as in Table 6). Once this understanding is settled, developing the intended blockchain-specific capabilities is a matter of the effective combination of learning mechanisms to fit blockchain technical and organizational dimensions. Both projects presented between and within variations (considering projects phases as illustrated in Figure 19). First, in the prototyping phase, both internal and external mechanisms were effectively implemented, without significant knowledge gaps arising. Consequently, both projects had similar duration in this phase. Although they differed in technical and organizational dimensions from the beginning, the learning efforts were in fit with required knowledge, mainly counting on external learning mechanism. However, after advancing to the next phase, it is possible to observe significant variations, given the fact that Petrobras learning linkages could not fully provide sufficient knowledge, especially in Beta product development phase, given (i) unequal blockchain technical levels, unfolded from the choice of a different implementation model by Petrobras, and (ii) lack of previous experience in more advanced blockchain organizational levels, a knowledge gap was filled by internal learning activities.

In relation to third question, on what business outcomes were obtained by Petrobras, this study found links between learning efforts and blockchain-specific capabilities accumulated by Petrobras with the innovation outputs and commercial results. To be clear, Petrobras' projects were not intended, from the beginning, to produce disruptive results. For example, Beta was created to reduce risks in a back-office process, which was sensible, but still not a business process. Moreover, Alpha had not even been planned to become more than a prototype. Therefore, we can assume that Petrobras started their accumulation path in blockchain technology using low-risk production activities, which is also observed in other companies that advanced blockchain projects to final product stage, e.g., Walmart in their coffee and bananas supply-chain tracking solution (KSHETRI, 2018). However, even with less ambitious goals, they provided qualitative gains in Petrobras' reputation, by reaffirming its innovative character, and in creating technological assets that can be reused in future blockchain applications. In Beta's case, the results were constrained by Petrobras learning efforts (not to be confused with lack of attention or lower work rates), as Beta project team had to change focus from external to internal mechanisms as the project progressed to the product development phase as explored above and fully detailed in 6.2.

7.2 Implications for blockchain innovation research

This study brings relevant contributions to the literatures on firm-level capability-building, innovation management and blockchain technology. First, this study combined insights from innovation literature to provide an analytical framework, which links several internal and external absorptive learning mechanisms (COHEN AND LEVINTHAL, 1990; FIGUEIREDO AND PIANA, 2018; FIGUEIREDO AND COHEN, 2019) with existing non-blockchain-specific capabilities to understand how firms' learning efforts affect the accumulation of blockchain-specific capabilities to create innovative activities and generating business outcomes to the firm. Furthermore, this study show how different internal and external mechanisms are activated to complement knowledge gaps.

Second, this study went beyond firm-level to investigate how teams accumulate innovative capabilities during blockchain projects, providing more detailed information over learn-by-doing and interactive learning through project phases. With effect, by making an additional analysis in the level of project phases, this study provided ways to compare variance between and within projects. Such approach was proven insightful

because it was possible to observe the changes in blockchain-specific capabilities accumulated by each project teams, and how different learning mechanisms took place and interacted with the blockchain dimensions.

Third, most studies on firm-level capability-accumulation treat innovative capabilities as a bundle of activities, routines, and physical technologies (BELL AND FIGUEIREDO, 2012; BELL AND PAVITT, 1995). Alternatively, some authors break down firm-level capabilities in technological functions or specific technologies (FIGUEIREDO, 2001; DANTAS AND BELL, 2011). This study analyzed bidimensional aspects in a single technology, and the implications in technical and organizational capabilities that are needed to create innovative outputs.

Fourth, studies on radical innovation (e.g., TRIPSAS AND GAVETTI, 2000) and evolutionary theory (NELSON AND WINTER, 1982) produce mixed conclusions over the role of existent capabilities on incumbent firms. Therefore, this study contributes with this debate by providing empirical evidence to support the argument that, in the case of blockchain in Petrobras, the non-blockchain-specific capabilities had a positive role in providing the learning linkages, technical infrastructure and multidisciplinary knowledge to project teams. Nonetheless, reflecting on how difficulties emerged when trying to internalize the prototypes created in external infrastructure into Petrobras' technological environment, there are indications that incumbents have more difficulties due to the more complex system, larger structures and number of routines, when compared with new entrants "because of their smaller size, shorter (path-dependent) histories, and more limited commitments to value networks and current technological paradigms" (MACHER AND RICHMAN, 2004).

Fifth, this study brings valuable contribution to blockchain literature as it based its findings in real-world projects, in which Petrobras and its partners had invested time and resources to absorb knowledge and produce real technology artifacts. As reported in the Literature Review section, blockchain literature is largely wanting in real-world blockchain systems. In this sense, this study adds to works such as Mengelkamp et al (2020) and Galati et al. (2021).

7.3 Implications for blockchain innovation practice

This study's contribution with practice is manyfold. First, it helps to clarify the nascent phenomenon of blockchain innovative projects in firms, showing how Petrobras had manage to articulate internal and external sources of knowledge to create innovative outputs. Second, it is important for managers to understand that decisions regarding the technical and organizational dimensions have repercussions on knowledge demand, which might be unavailable at some point. In the face of such dependency, managers need to know if changes are necessary, and how much their learning efforts should be increased to achieve the desired level of innovation. Third, even though reaching higher innovative levels, Petrobras innovation outputs had still some limitations, given blockchain low maturity levels. Although Petrobras, as many other major companies, are experimenting with this technology because of its potential disruptive nature, in projects to benefit supporting processes, which present lower risks, compared with productive activities at least. Finally, managers are often confused by blockchain technology. Joia and Vieira (2018) found that even Brazilian ICT technicians do not know exactly what is blockchain, and there is evidence that this behavior is observed even in developed countries due to all the hype created around it and mixed messages received by decision makers (GARTNER, 2019). Moreover, the high rates of failures in blockchain projects (MALONEY, 2018) represent wasting of valuable time and resources. Therefore, every empirical study that contributes to clarify any aspect of blockchain innovative projects is worthy to the economic activity, especially investigations such as undertaken in this study, bringing lessons from real-world problems, which can be assimilated to accelerate technological advances in emerging economies.

7.4 Limitations

There are limitations in the study, such as the small sample, and the fact that most of interviewees work for Petrobras, and directly participated in the projects. If, on the one hand, it was possible to obtain more details, increasing internal validity, on the other hand, further research is necessary to allow generalizations. Moreover, this study creates links with existing capabilities and learning efforts, however it does not investigate the accumulation paths for each technological capability to understand how capabilities in each function affected positively or negatively the accumulation process, although the product of their interactions seemed positive. Finally, there were no observation of new-

to-world blockchain applications created by Petrobras in the period, which left this category only in a somehow speculative theoretical situation.

7.5 Suggestions for further research

Further research is needed to establish external validity of the findings in this study. Therefore, obtaining more data from real-world blockchain projects in latecomer firms is germane. Moreover, as blockchain technology is a fertile ground to start-ups, it was enlightening to observe how small firms undertake their blockchain projects, in order to understand the main differences, especially in the role of existent non-blockchain-specific capabilities in their learning efforts. Finally, this study focused on Petrobras' technology demand, which is still relatively low when compared with other digital technologies (e.g., machine learning, HPC, digital twins). Not coincidentally, the projects aimed low-risk processes and relatively smaller learning efforts were undertaken. This behavior might be different on the blockchain supply side, as mastering the technology might give competitive advantages to those firms, and different mechanisms might exist in this effervescent context.

7.6 Conclusion

In conclusion, the findings reported in this study have relevant implications to firm-level capability accumulation, innovation management and blockchain literatures, especially in the context of emerging economies. It contains indications that external sources are the main catalyst of new knowledge in blockchain, but internal skills are also pivotal in identification of most suited cases for using blockchain in innovative activities, in absorbing, disseminating, and reinforcing external knowledge in the company. However, such internal skills need also to be used proactively, activating internal knowledge creation mechanisms to remove possible knowledge gaps. Given that blockchain is very immature currently, it seems very unlikely that all the required knowledge is in the hands of external sources alone, regardless their capabilities. In special, organizational dimensions of blockchain innovative activities should be well understood, as findings in this study points to negative effects when partners capabilities do not fit with the required levels in both technical and organizational, and it is often difficult to foresee ex-ante. Moreover, this study brings insightful methods to analyze innovative activities in emerging technologies, where not much firm-level data is available. Although limited to observations over two projects, it was possible to observe the role of existing non-blockchain-specific capabilities in the creation of new

blockchain-specific knowledge. Finally, this study brings recommendations to future investigations over smaller firms, and in capability-accumulation process on firms competing in the supply side of blockchain technology.

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