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Research Article

Unveiling the role of frugal and digital capabilities in the financing of deep tech startups

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Abstract

Objective: Showcasing the Role of Digital Technologies, Frugal Innovation, and Imitability Attributes in Attracting Investments in Deep Tech Startups in an Emerging Economy. **Methodology/approach:** The primary data for this research were obtained from a sample of 216 deep tech startups from various sectors, located in São Paulo. The hypotheses were tested using structural equation modeling through the Partial Least Squares (PLS-SEM) method. **Main results:** Private investors are attracted to digital technologies and the attribute of being difficult to imitate. However, although there is a positive association between the capacity for frugal innovation and the hard-to-imitate attribute, no indirect effects of this capacity on investments were identified. **Theoretical/methodological contributions:** Focusing on emerging economies, this study contributes to the literature that investigates which factors explain investments in deep tech startups. Moreover, it contributes to the literature linking frugal innovation and technological complexity. **Relevance/originality:** Deep tech startups require substantial financial resources; however, in emerging markets, there is a scarcity of investment resources. Based on the RBV (Resource-Based View), this research demonstrates which capabilities are able to arouse the interest of private investors in the context of emerging economies. **Social/management contributions:** For entrepreneurs, the research highlights the importance of digital technologies in attracting investments. For investors and public policy makers, the study emphasizes the association of the capacity for frugal innovation with the attribute of imitability in deep tech startups.

Keywords: Startups deep tech. Investments. Frugal innovation. Digital technologies.

Revelando o papel das capacidades frugais e digitais no financiamento de startups de deep tech

Resumo

Objetivo: Demonstrar o Papel das Tecnologias Digitais, Inovação Frugal e Atributos de Imitabilidade na Atração de Investimentos em *Startups* de *Deep Tech* em uma Economia Emergente. **Metodologia/abordagem**: Os dados primários para esta pesquisa foram obtidos de uma amostra de 216 *startups* de *deep tech* de vários setores, localizadas em São Paulo. As hipóteses foram testadas utilizando modelagem de equações estruturais através do método *Partial Least Squares* (PLS-SEM). **Principais resultados**: Investidores privados são atraídos por tecnologias digitais e pelo atributo de ser difícil de imitar. No entanto, embora exista uma associação positiva entre a capacidade de inovação frugal e o atributo difícil de imitar, não foram identificados efeitos indiretos dessa capacidade sobre os investimentos. **Contribuições teóricas/metodológicas**: Focando em economias emergentes, este estudo contribui para a literatura que investiga quais fatores explicam os investimentos em *startups* de *deep tech*. Além disso, contribui para a literatura que liga a inovação frugal e a complexidade tecnológica. **Relevância/originalidade:** *Startups* de *deep tech* requerem recursos financeiros substanciais; no entanto, em mercados emergentes, há escassez de recursos de investimento. Baseado na Visão Baseada em Recursos (RBV), esta pesquisa demonstra quais capacidades são capazes de despertar o interesse de investidores privados no contexto de economias emergentes. **Contribuições sociais/gerenciais**: Para empreendedores, a pesquisa destaca a importância das tecnologias digitais na atração de investimentos. Para investidores e formuladores de políticas públicas, o estudo enfatiza a associação da capacidade de inovação frugal com o atributo de imitabilidade em *startups* de *deep tech*.

Palavras-chave: *Startups deep tech*. Investimentos. Inovação frugal. Tecnologias digitais.

INTRODUCTION

Financing instruments are crucial for deep tech startups (De la Tour et al., 2021; Nedayvoda et al., 2021). Deep tech startups are ventures based on scientific discoveries and advanced technologies (Chaturvedi, 2015) and aim to address complex social and environmental challenges globally (Nedayvoda et al., 2021). They face numerous challenges, such as high uncertainties related to technology and market, information asymmetries, and greater needs for financial resources and time compared to other startups. This significantly increases the risk level for investment sources (Gigler & McDonagh, 2018; Nedayvoda et al., 2021). The literature has sought to identify factors that can reduce these obstacles and influence the attraction of investment in deep tech startups. Some factors, such as the entrepreneurial ecosystem and alliances between companies, are external to the startups (Hoenig & Henkel, 2015; Kriz et al., 2022), while others, such as human capital and intellectual property (Huayamares et al., 2022; Madsen et al., 2008), are internal. For the purposes of this research, based on RBV (Resource-Based View) (Barney, 1991), the focus is on internal factors that influence the attraction of investments in deep tech startups in emerging economies.

According to the RBV, companies attract investments by strengthening their strategic capabilities. For example, technological capabilities, which are defined as competencies, knowledge, and skills necessary for a company to effectively use technology and convert inputs into solutions (Mikalef et al., 2020). They allow startups to develop disruptive solutions in their respective sectors. However, in emerging markets, companies face numerous constraints, such as market limitations, resource scarcity, and infrastructure inadequacies (Niroumand et al., 2021), in addition to regulatory complexities (Asakawa et al., 2019; Barnikol & Liefner, 2022). In this scenario, recent research shows that frugal innovation has emerged as a fundamental capability for companies in emerging economies (Asakawa et al., 2019; Rossetto et al., 2023). Frugal innovation involves reducing the complexity and costs of operation and use, while meeting the quality standards demanded by the market (Weyrauch & Herstatt, 2017). For example, ventilators developed during the Covid-19 pandemic (Rossetto et al., 2023). Consequently, the capacity for frugal innovation can generate social, environmental, and economic value (Rossetto et al., 2023) and increase performance (Bedi & Vij, 2016; Cai et al., 2019; Cuevas-Vargas et al., 2022) in resource-scarce environments. However, frugal innovations are often associated with low technological complexity (Zeschky et al., 2011), which may compromise the development of unique and hard-to-replicate innovations, thus discouraging investments in deep tech startups that possess this capability. In this scenario, although there is a growing stream of research on capabilities and investments in deep tech startups, the links between technological capabilities, frugal innovation capacity, and private investments in emerging markets remain unexplored. Therefore, the following research question arises: What role do technological capabilities and the capacity for frugal innovation play in attracting investments in deep tech startups located in emerging economies?

The objective of this research is to examine the association between technological and frugal innovation capabilities and the attraction of investments in deep tech startups in an emerging economy. Furthermore, it seeks to investigate the mediating role of the imitability attribute in this relationship. To achieve these objectives, primary data were collected from 216 deep tech startups in various sectors, located in the state of São Paulo. These data were analyzed through structural equation modeling using partial least squares estimation (PLS-SEM). As a result, a statistically significant association was found between technological capabilities and private investments, regardless of the imitability attribute. However, although frugal innovation qualifies as difficult to imitate, no statistically significant association was found between the capacity for frugal innovation and the attraction of private investments.

This research intends to present three contributions to the literature. Firstly, most of what is known about deep tech startup financing comes from advanced economies (Nedayvoda et al., 2020; Startup Genome, 2023). However, startups located in advanced economies do not face the restrictions commonly found in emerging economies. Thus, this research adds to the literature on financing deep tech startups, focusing on an emerging economy. Secondly, although the RBV suggests the importance of the imitability attribute, there is a lack of understanding about whether this attribute can boost the indirect effect of technological capabilities on attracting private investments. In this sense, this study contributes to the literature by empirically testing whether the imitability attribute leads to greater attraction of private investments in deep tech startups. Thirdly, by focusing on whether deep tech startups that possess frugal innovation capability can develop hard-to-imitate innovations, this study fills a gap on frugal innovation and technological complexity (Rao, 2017; 2019). Additionally, the research brings managerial contributions to entrepreneurs, investors in deep tech startups, and public policy makers in science, technology, and innovation in emerging economies. Entrepreneurs of deep tech startups should ensure the use of digital technologies to increase the attraction of investments, as well as clearly demonstrate to investors the strategic potential of frugal solutions. Investors in deep tech startups should pay attention to the competitive advantage of solutions that are difficult to imitate and recognize the strategic role played by the capacity for frugal innovation for the success of startups in emerging markets. Public policy makers in science, technology, and innovation in emerging economies should develop specific support lines for businesses based on frugal solutions, which have the potential to address external income and infrastructure constraints present in emerging economies and are still opportunities little explored by private investors.

THEORETICAL FRAMEWORK

Financing of deep tech startups

Funding instruments are essential for startups (Lefebvre et al., 2022). Steve Blank (2013) defines a startup as "a temporary organization designed to pursue a repeatable and scalable business model." Eric Ries (2011) characterizes it as "a human institution designed to create a new product or service under conditions of extreme uncertainty." In general terms, the literature considers startups to be innovation-oriented organizations in their initial phases (Skala, 2018). This research focuses on deep tech startups, which are organizations in their early stages supported by scientific discoveries and technological advances, aiming to solve complex social and environmental challenges on a global scale.

Deep tech startups obtain funding in their early stages from both public and private sources (Hegeman & Sørheim, 2021; Scarpellini et al., 2018; Marcus et al., 2013). Public sources can take a variety of forms, such as awards, government support programs, tax incentives, among others (Johnson & Wagoner, 2021). Private sources can be internal and external. Internal sources represent the investments provided by the entrepreneurs themselves, their family, and friends (Aranda-Usón et al., 2019). External sources involve angel investors, venture capital, corporate venture capital, private equity, and banks.

However, deep tech startups face a series of challenges in accessing external private investment sources (Gigler & McDonagh, 2018; Nedayvoda et al., 2021). Firstly, these companies present high uncertainties related to the market and technological viability (Miozzo & DiVito, 2016; Gigler & McDonagh, 2018). Secondly, severe information asymmetries hinder the evaluation and monitoring of deep tech startups by investors (Miozzo & DiVito, 2016). Thirdly, developing solutions in deep tech startups requires more financial resources and time than other startups. For example, in

the biopharmaceutical industry, it takes an average of 15 years to reach the market (Miozzo & DiVito, 2016). These characteristics significantly increase the level of risk for investors.

Despite the challenges faced by deep tech startups in accessing investment sources, there has been an increase in interest from private investors in recent years (De la Tour et al., 2021; Nedayvoda et al., 2020). From 2016 to August 2021, investment in deep tech startups through venture capital exceeded $307 billion, with nearly $78 billion invested in just the first eight months of 2021 (Nedayvoda et al., 2021). Additionally, angel investors are driving deep tech startups in emerging economies (Nedayvoda et al., 2020). These initiatives reflect the increasing interest of angel investors, venture capital, and corporate venture capital in investing in deep tech startups.

In this context, research seeks to identify the elements that investors consider when investing in deep tech startups (Cockburn & MacGarvie, 2009; Hsu & Ziedonis, 2013; Huayamares et al., 2022; Kriz et al., 2022). These elements include external factors, such as the entrepreneurial ecosystem (Kriz et al., 2022) and alliances (Doblinger et al., 2019), and internal factors, such as human capital (Baum & Silverman, 2004; Lefebvre et al., 2022) and intellectual property (Cockburn & MacGarvie, 2009; Hsu & Ziedonis, 2013; Huayamares et al., 2022). The literature reveals that although external factors are important to investors, they direct their resources to deep tech startups that demonstrate competitive advantage over their competitors. For this reason, internal factors have a significant impact on attracting investments. Therefore, to attract investment sources, it is essential that deep tech startups strengthen their capabilities and resources that ensure their competitive advantage over their competitors.

The role of capabilities in attracting financing for deep tech startups

The Resource-Based View (RBV) suggests that companies gain a competitive advantage by developing strategic resources and capabilities, i.e., resources and capabilities that are valuable, rare, difficult to imitate, and non-substitutable (Barney, 1991). In this context, a resource is defined as "an asset or input for production (tangible or intangible) that the organization owns, controls, or has access to on a semi-permanent basis" (Helfat & Peteraf, 2003, p. 3). Capability refers to "the ability of the organization to perform a coordinated set of tasks, utilizing organizational resources, for the purpose of achieving a particular end result" (Helfat & Peteraf, 2003, p. 3).

The literature recognizes that strategic resources and capabilities have a positive effect on attracting investments in deep tech startups. For example, research has demonstrated that intellectual property (Hsu & Ziedonis, 2013) and human capital (Baum & Silverman, 2004; Lefebvre et al., 2022) are fundamental in attracting investors. Studies also show that investors are particularly attracted to startups focused on digital technologies (Hidayat et al., 2022; OECD, 2021). Digital technologies are drastically changing competition, causing disruptions in markets (Chanias et al., 2019; Frank et al., 2019; Vial, 2019; Warner & Wäger, 2019). They facilitate the combination of resources and capabilities to generate new forms of digital offerings, reducing the entry cost in many sectors (Vial, 2019). Moreover, in emerging economies, digital technologies can fill market gaps, offering solutions that help overcome challenges and drive sustainable development. Thus, technological capabilities can be essential for deep tech startups in emerging economies. Technological capabilities are understood as: competencies, knowledge, and skills necessary for a company to effectively use technology and convert inputs into products (Mikalef et al., 2020). In this way, by combining technological capabilities with the specific needs of consumers in emerging economies, deep tech startups have the opportunity to create disruptive solutions and attract the interest of private investors. Based on this, we propose the following hypothesis:

H1: Technological capabilities are positively associated with attracting private investments in deep tech startups in emerging economies.

On the other hand, although the capacity for frugal innovation is considered an essential strategic capability for value creation (Santos et al., 2020; Rao, 2019) and for the performance of companies located in emerging economies (Bedi & Vij, 2016; Cai et al., 2019; Cuevas-Vargas et al., 2022), it may exert a negative influence on attracting investments in deep tech startups. Frugal innovation can be defined as high-value (environmental, social, and economic) solutions (products, processes, marketing methods, and organizational) developed with minimal resource use (Bedi & Vij, 2016) that cater to both emerging and advanced markets (Rao, 2017; Santos et al., 2020; Zeschky et al., 2014). More specifically, the capacity for frugal innovation refers to the company's ability to recognize and meet the essential needs of customers (Weyrauch & Herstatt, 2017), to substantially reduce operation and usage costs (Rao, 2017), and to establish partnerships with various stakeholders, such as local communities, companies, universities, non-governmental organizations, and governments, to achieve objectives related to environmental, social, and economic sustainability (Rossetto et al., 2023). Therefore, frugal innovations aim to meet the essential needs of customers that have not yet been satisfied, such as accessibility, good quality, easy operation, basic functionality, low cost of ownership and use, robustness, among other aspects (Weyrauch & Herstatt, 2017).

However, frugal innovations are often perceived as inferior to existing solutions due to their limited functionality and the use of simpler and more economically accessible materials (Zeschky et al., 2011). For this reason, the capacity for frugal innovation can generate concerns among investors regarding the competitiveness of the developed solutions. Specifically in deep tech startups, where technological complexity is high, the capacity for frugal innovation may be seen as an obstacle in attracting investors, as they are interested in advanced and disruptive technologies. As a result, in deep tech startups, the capacity for frugal innovation tends to discourage private investments. Based on this, we propose the following hypothesis:

H2: The capacity for frugal innovation is negatively associated with attracting investments in deep tech startups in emerging economies.

Additionally, both technological capabilities and the capacity for frugal innovation can play an essential role when combined with the difficult-to-imitate attribute in deep tech startups in emerging economies, adding value to private investors. In this way, when other startups face difficulties in replicating the technological solutions developed, the technological capability becomes even more attractive for private investments in deep tech startups in emerging economies. Digital technologies can transform consumer behavior and provide numerous opportunities for interactions and co-creation (Chanias et al., 2019; Frank et al., 2019; Warner & Wäger, 2019). With the aid of new research tools and social media, consumers have become more connected, informed, empowered, and active, contributing to the production of various content (Verhoef et al., 2021). In this way, by adopting digital technologies, deep tech startups can create numerous experiences for their customers, which favors the construction of difficult-to-imitate solutions. Therefore, this study argues that the effective use of digital technologies creates experiences that make it difficult to imitate the technological solutions developed by deep tech startups, which in turn, should increase the attraction of private investments. Therefore, we propose the following hypothesis:

H3a: Technological capabilities are positively associated with the difficult-to-imitate attribute in deep tech startups in emerging economies.

H3b: The relationship between technological capabilities and attracting investments in deep tech startups in emerging economies is positively mediated by the difficult-to-imitate attribute.

Similarly, when it is difficult for other startups to replicate the technological solutions developed through the frugal innovation approach, the capacity for frugal innovation becomes attractive for private investments in deep tech startups in emerging economies. Frugal innovation capacity involves the combination of unique internal processes, acquired over time, which are capable of identifying opportunities and developing solutions suitable for market needs (Bedi & Vij, 2016). Moreover, frugal innovation capacity promotes collaborations with various actors in the local entrepreneurial ecosystem, such as universities (Fischer et al., 2021), partner companies (Rossetto et al., 2023), government (Sharmelly & Ray, 2018), and NGOs (Sharmelly & Ray, 2018). Thus, the capacity for frugal innovation can enhance the ability of deep tech startups to anticipate market changes and seize business opportunities in emerging markets. Therefore, this study considers that if the frugal innovation capacity allows the deep tech startup to develop solutions that are difficult for other startups to replicate, it becomes attractive for private investments. Thus, we propose the following hypothesis:

H4a: The capacity for frugal innovation is positively associated with the attribute of being difficult to imitate in deep tech startups in emerging economies.

H4b: The relationship between the capacity for frugal innovation and the attraction of investments in deep tech startups in emerging economies is positively mediated by the attribute of being difficult to imitate.

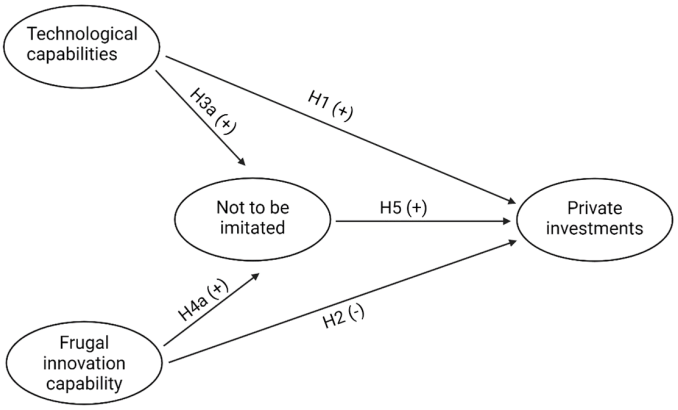
The RBV emphasizes the importance of valuable, rare, difficult to imitate, and non-substitutable resources in securing a company's competitive advantage (Barney, 1991). Particularly, deep tech startups are prone to develop valuable, rare, and irreplaceable solutions, since they incorporate highly specialized knowledge (Miozzo & DiVito, 2016), operate within complex collaboration networks (Doblinger et al., 2019), and make substantial investments in research and development over several years (Gigler & McDonagh, 2018; Nedayvoda et al., 2021). However, a significant challenge for these companies lies in meeting the difficult-to-imitate attribute. The rapid dissemination of knowledge to competitors shortens the window of opportunity to capitalize on scientific and technological innovations (Miozzo & DiVito, 2016), making it hard to maintain the exclusivity of their solutions. Thus, the ability to ensure that their solutions are difficult to imitate becomes a crucial criterion for investors when assessing the investment potential in deep tech startups.

Essentially, even if a deep tech startup possesses valuable, rare, and irreplaceable resources, its ability to attract investment depends primarily on its ability to demonstrate that its solution is complex enough to resist imitation. This need is particularly pronounced in emerging markets, where access to financing is more limited and market conditions are more volatile and risky. In this environment, deep tech startups that can first demonstrate that their solutions are complex enough to resist imitation stand a better chance of attracting investments. Thus, being difficult to imitate, especially for deep tech startups in emerging economies, establishes a sustainable competitive advantage over competitors, playing a crucial role in attracting the interest of private investors. Based on this, we propose the following hypothesis:

H5: The attribute of being difficult to imitate is positively associated with the attraction of private investments in deep tech startups in emerging economies.

Figure 1

Research model



Note: **Description of the relationships**
H1 (+): Technological capabilities → Private investments
H2 (-): Frugal innovation capability → Private investments
H3a (+): Technological capabilities → Not to be imitated → Private investments
H4a (+): Frugal innovation capability → Not to be imitated → Private investments
H5 (+): Not to be imitated → Private investments
Elaborated by the authors.

METHODOLOGY

Approach and method

The methodological approach adopted in this study was quantitative in nature. Data were collected from deep tech startups in any sector, located in the state of São Paulo. To test the hypotheses, a sample was constructed by combining companies listed in the database of the Innovative Research in Small Companies Program (in portuguese: Programa de Pesquisa Inovadora em Pequenas Empresas - PIPE) of the São Paulo Research Foundation (in portuguese: Fundação de Amparo à Pesquisa do Estado de São Paulo - FAPESP), from 2017 to 2021, along with companies indicated by actors linked to the environments accredited in the São Paulo System of Innovation Environments (in portuguese: Sistema Paulista de Ambientes de Inovação – SPAI), a network of innovation environments created by the state government of São Paulo. This approach allowed the identification of 1024 companies. For the sample selection, five criteria were established. Firstly, the startups had to be registered in the State of São Paulo, with an active CNPJ. Secondly, it was required that the solution proposed by the startup incorporate specific advanced technologies. These technologies included artificial intelligence, machine learning, big data, Internet of Things (IoT), drones and unmanned aerial vehicles (UAVs), blockchain, biotechnology, nanotechnology, sensors and biosensors, biomaterials and innovative materials, additive manufacturing, augmented reality, virtual reality, robotics, and bioinformatics. Furthermore, it was essential for this solution to already be generating tangible results for society and to have the potential to provoke changes in the industry in which it is inserted. Finally, the startups had to have a website and/or social media with updated information. The application of these five criteria produced a sample of 373 deep tech startups. An online structured questionnaire was adopted for the collection of cross-sectional primary data.

Data collection technique

The online structured questionnaire was sent via email to 373 deep tech startups between March and April 2022. The respondents were the CEOs of these startups. A total of 220 valid responses were received. The sample size was estimated using the G*Power software version 3.1.9.4, with the following parameters: effect size f2 of 0.15 (medium effect) (Cohen, 1998); statistical power of

0.80 (Hair et al., 2020), significance level of 0.05 (Hair et al., 2020), and three predictors. These parameters resulted in a minimum sample size of 77, and this requirement was met with the 216 valid responses obtained, after excluding 4 outliers.

The questionnaire was developed with variables measured on a binary scale (Yes/No). This measure was adopted to increase the response rate, as the respondents were the CEOs of the startups. The survey adapted previously established and validated scales to measure the constructs (Table 1).

The frugal innovation capacity construct was based on Rossetto et al. (2023). This scale consists of ten items: main functionality, easy to use, durability, good value products, cost reduction, economical manufacturing, process reorganization, socio-environmental satisfaction needs, sustainable production, and partnership in the production process. The technological capabilities construct was adapted from the literature (AlNuaimi et al., 2021; Karim et al., 2019; Mikalef et al., 2020) and consists of four items: Big Data; IoT, Artificial Intelligence, and Machine Learning. The private investments construct was adapted from the literature (Scarpellini et al., 2018; Aranda-Usón et al., 2019; Hegeman & Sørheim, 2021), consisting of 5 items: angel, pre-seed; seed; venture capital; and corporate venture capital. Similarly, the attribute of not being easily imitated is a binary variable that was adapted from Barney (1991).

Data analysis technique

The analysis was conducted through structural equation modeling with partial least squares estimation (PLS-SEM). Since the data are binary variables, some procedures were carried out before the analysis. Initially, the values of the items were summed to obtain a single representative value for each construct. For example, the ten items related to frugal innovation were summed, providing a value that represents the overall involvement of startups in this construct. After summing the items for each construct, z-scores were calculated. These steps allowed the structural model analysis through SmartPLS 4 software.

RESULTS

Most of the startups included in the sample have been operational for less than 5 years (45%) and between 6 to 10 years (44%). Startups older than 11 years represent a smaller proportion (11%). Although most startups are in their early years of operation, it was noted that the majority of technologies are in more advanced stages of development, from the pre-commercial phase (TRL8) to the application of technology in the market (TRL9). These two phases combined account for 63% of the developed solutions. The initial stages of basic technological research (TRL1) and technology formulation with the survey of possible applications (TRL2) have smaller proportions, 1% and 2% respectively, indicating that most of the solutions have already passed through these initial stages (Table 2).

The structural model was evaluated based on collinearity, the coefficient of determination (R^2), effect size (f^2), predictive validity (Q^2), and the relationships between the constructs and their significance. The model's collinearity assessment was tested using the variance inflation factor (VIF). The highest VIF value was 1.048, indicating that there are no multicollinearity problems in the study (Hair & Alamer, 2022).

Regarding the coefficient of determination (R^2), for investments, the adjusted R^2 of 0.107 indicates that the combination of frugal innovation, not being easily imitated, and technological capabilities

Table 1

Variables utilized in the research

Variables	Variable Calculation	Source
Frugal innovation	Dummy, with a value of "1" for the startup that, in the development of the solution, attached great importance to the core functionality of the product rather than additional functionality; and a value of "0" otherwise.	Rossetto et al. (2023)
	Dummy, with a value of "1" for the startup that, in the development of the solution, attributed great importance to the ease of use of the product; and a value of "0", otherwise.	
	Dummy, being a value of "1" for the startup that, in the development of the solution, attributed great importance to the question of the durability of the product (does not spoil easily); and a value of "0", otherwise.	
	Dummy, with a value of "1" for the startup that, in the development of the solution, attached great importance to solutions that offer "good-value" products; and a value of "0", otherwise.	
	Dummy, with a value of "1" for the startup that, in the development of the solution, attributed great importance to the significant cost reduction in the operational process; and a value of "0", otherwise.	
	Dummy, with a value of "1" for the startup that, in the development of the solution, attributed great importance to the savings of organizational resources in the operational process; and a value of "0", otherwise.	
	Dummy, with a value of "1" for the startup that, in the development of the solution, attributed great importance to the rearrangement of organizational resources in the operational process; and a value of "0", otherwise.	
	Dummy, being a value of "1" for the startup that, in the development of the solution, attached great importance to efficient and effective solutions to customers' social/environmental needs; and a value of "0", otherwise.	
	Dummy, with a value of "1" for the startup that, in the development of the solution, attributed great importance environmental sustainability in the operational process; and a value of "0", otherwise.	
	Dummy, with a value of "1" for the startup that, in the development of the solution, attributed great importance to partnerships with local companies in the operational process; and a value of "0", otherwise.	
Technological Capabilities	Dummy, with a value of "1" for the startup that signaled the use of Big Data; and a value of "0", otherwise.	AlNuaimi et al. (2021); Karim et al. (2022); Mikalef et al. (2020)
	Dummy, with a value of "1" for the startup that signaled the use of IoT; and a value of "0", otherwise.	
	Dummy, with a value of "1" for the startup that signaled the use of Artificial Intelligence; and a value of "0", otherwise.	
	Dummy, with a value of "1" for the startup that signaled the use of Machine Learning; and a value of "0", otherwise.	
Private Investments	Dummy, with a value of "1" for the startup that signaled the receipt of angel investment; and value "0" otherwise.	Scarpellini et al. (2018); Aranda-Usón et al. (2019); Hegeman and Sørheim (2021)
	Dummy, with a value of "1" for the startup that signaled the receipt of pre-seed; and value "0" otherwise.	
	Dummy, with a value of "1" for the startup that signaled the receipt of seed; and value "0" otherwise.	
	Dummy, with a value of "1" for the startup that signaled the receipt of venture capital; and value "0" otherwise.	
	Dummy, with a value of "1" for the startup that signaled the receipt of corporate venture capital; and value "0" otherwise.	
Not to be imitated	Dummy, with a value of "1" for the startup that signaled that its solution cannot be easily imitated; and a value of "0" otherwise.	Barney (1991)

Note: Elaborated by the authors.

explain approximately 10.7% of the variation in investments. For the attribute of not being easily imitated, the adjusted R^2 of 0.037 indicates that frugal innovation and the use of digital technologies explain approximately 3.7% of the variation of the attribute of not being easily imitated.

Table 2

Sample Characteristics

Age	**N**	**%**
Up to 5 years	96	45
6 – 10 anos	95	44
Over 11 years	25	11
Technology readiness level		
Basic principles observed (TRL1)	3	1
Technology concept formulated (TRL2)	4	2
Experimental proof of concept (TRL3)	19	9
Technology validated in laboratory (TRL4)	16	7
Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies) (TRL5)	9	4
Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies) (TRL6)	17	8
System prototype demonstration in operational environment. (TRL7)	12	6
System complete and approved (TRL8)	24	11
Actual system proven in its operational environment (competitive manufacturing in the case of key enabling technologies; or in space) (TRL9)	112	52

Note: Elaborated by the authors.

The effect size was analyzed following Cohen's (1988) formula, which classifies values as weak, moderate, and strong, with 0.02, 0.15, and 0.35, respectively. Based on this, it can be observed that frugal innovation does not have a significant effect on investments ($f^2 = 0.005$), while not being imitated ($f^2 = 0.023$) and technological capabilities ($f^2 = 0.101$) show a weak and near-moderate effect on investments, respectively. Regarding predictive validity, investments and not being easily imitated have a Q^2 greater than 0, indicating a good predictive power of the model for these variables, as recommended by Chin (1998).

The bootstrapping approach with 5000 samples was employed to determine the statistical significance of the path coefficients. Hypothesis 1 predicts that technological capabilities are positively associated with the attraction of private investments in deep tech startups in emerging economies. The results indicate a statistically significant direct association of technological capabilities with the attraction of private investments ($\beta = 0.300$, $p < 0.01$), supporting H1. Hypothesis 2 predicts that the capacity for frugal innovation is negatively associated with the attraction of investments in deep tech startups in emerging economies. The results indicate that there is no statistically significant direct association of frugal innovation capacity with private investments ($\beta = -0.068$, $p > 0.05$). Thus, hypothesis 2 was rejected. Hypothesis 3a predicts that technological capabilities are positively associated with the attribute of being difficult to imitate in deep tech startups in emerging economies, while H3b predicts that the relationship between technological capabilities and the attraction of investments in deep tech startups in emerging economies is positively mediated by the attribute of being difficult to imitate. The results indicate that there is no direct effect of technological capability on the attribute of being difficult to imitate ($\beta = 0.047$, $p > 0.05$), rejecting H3a. Similarly, the results indicate that there is no indirect effect of technological capability on the attraction of investments ($\beta = 0.014$, $p > 0.05$), rejecting H3b. Hypothesis 4a predicts that the capacity for frugal innovation is positively associated with the attribute of being difficult to imitate in deep tech startups in emerging economies, while 4b predicts that the relationship between the capacity for frugal innovation and the attraction of investments in deep tech startups in emerging economies is positively mediated by the attribute of being difficult to imitate. The results indicate a statistically significant direct association of frugal innovation capacity with the attribute of being difficult to imitate ($\beta = 0.093$, $p < 0.01$), supporting H4a. However, the results indicate that there are no positive indirect effects of frugal innovation capacity on private investments ($\beta = 0.027$, $p > 0.05$), rejecting H4b. Finally, hypothesis 5 predicts that the attribute of being difficult to imitate is positively associated with the attraction of private investments in deep tech startups in emerging economies. The results indicate a statistically significant direct association of the attribute of being difficult to imitate with the attraction of private investments ($\beta = 0.293$, $p < 0.05$), supporting H5 (Table 3).

DISCUSSION

Based on the Resource-Based View (RBV), this research contributes to the literature in three ways. Firstly, it expands the literature on investments in deep tech startups by investigating two distinct capabilities - technological capabilities and frugal innovation capacity - and their relationships with private investments in deep tech startups in emerging economies. The results show that for deep tech startups in emerging economies, technological capabilities are significantly related to private investments. These findings are in line with research conducted in advanced economies (Hoenig & Henkel, 2015; Hsu & Ziedonis, 2013). However, this research brings a new perspective by demonstrating that the use of digital technologies, such as big data, IoT, AI, and machine learning, in emerging markets plays a crucial role in attracting investments, regardless of the sector in which the startup operates.

Secondly, the research findings also contribute to the literature by suggesting that developing solutions that are difficult to imitate is not necessarily a determining factor in the relationship between

Table 3

Hypothesis test results

Effect	H	Structural Relations	Coefficient	Standard Error	t-value	p-value	Result
Direct	H1	TEC → INV	0.300	0.060	5.025	0.000	Accepted
	H2	IF → INV	-0.068	0.064	1.057	0.290	Rejected
	H3a	TEC → N_IMIT	0.047	0.033	1.435	0.151	Rejected
	H4a	IF → N_IMIT	0.093	0.034	2.754	0.006	Accepted
	H5	N_IMIT → INV	0.293	0.132	2.225	0.026	Accepted
Indirect	H3b	TEC → INV	0.014	0.013	1.103	0.270	Rejected
	H4b	IF → INV	0.027	0.017	1.622	0.105	Rejected

Note: Elaborated by the authors.

technological capabilities and the attraction of investments. Instead, the use of digital technologies appears to be a more influential aspect for attracting investments than the exclusivity of the developed solutions. A possible explanation for these results is that digital technologies play a fundamental role in creating and appropriating value (Dubey et al., 2019). Digital technologies provide startups with the ability to adapt to the demands and needs of emerging markets over an extensive period of technological development. Research shows that when organizations utilize digital technologies, they become more agile and capable of quickly adapting to changes in the business environment (Verhoef et al., 2021). Thus, digital technologies help deep tech startups improve strategic decision-making and mitigate risks, generating investor confidence as they view the startup as more prepared and capable of facing the challenges of emerging markets. Additionally, digital technologies are characterized by high scalability (Verhoef et al., 2021), which also increases investor interest (Lange, 2017). Therefore, to attract private investments, it is essential for deep tech startups to demonstrate the adoption of digital technologies.

Thirdly, this study contributes to the literature on frugal innovation in deep tech startups. The results reveal that the capacity for frugal innovation does not have a negative effect on the attraction of private investments. Furthermore, a positive relationship was identified between frugal innovation and the difficulty of imitating the solutions developed by deep tech startups. These results support the perspective that combining the frugal approach with science and the application of advanced technology, defined as "advanced frugal innovation" (Rao, 2017; 2019), can provide a competitive advantage (Barnikol & Liefner, 2022). Advanced frugal innovation emerges as an effective response to external constraints prevalent in emerging markets, such as income limitations (Barnikol & Liefner, 2022), resource scarcity (Rossetto et al., 2023), infrastructure inadequacies (Niroumand et al., 2021), and regulatory complexities (Asakawa et al., 2019), among other similar challenges. In this perspective, startups have been actively incorporating advanced frugal innovations into their operations, redefining how they conduct activities in different sectors (Zahra, 2021). By developing advanced frugal innovation, deep tech startups are enabled to face the specific challenges found in emerging markets, standing out in their respective sectors. However, the statistical analysis did not show a significant indirect effect of frugal innovation capacity on attracting investments through the attribute of being difficult to imitate. This indicates that investors have not yet fully recognized the strategic role played by frugal innovation capacity. A possible explanation for this lies in the fact that advanced frugal innovations present an unconventional nature, and thus, are not perceived as distinctive and difficult-to-replicate solutions. Therefore, it is crucial for deep tech startups to demonstrate to private investors that their frugal solutions, integrating science and technology, are based on unique and complex social context phenomena. By doing so, startups can pique the interest of these investors and increase their investments.

This article reveals managerial contributions for entrepreneurs of deep tech startups, investors of deep tech startups, and public policy makers in science, technology, and innovation in emerging economies.

For entrepreneurs of deep tech startups, regardless of the sector they operate in, the use of digital technologies indicates an increase in the attraction of investments. Digital technologies, such as big data, IoT, AI, and machine learning, heighten investor interest as they are connected to concepts of scalability and the ability to quickly adapt the enterprise to changes in the business environment. Entrepreneurs should also consider developing frugal innovation to gain a competitive edge and stand out in their sectors. To attract investors' interest in frugal solutions, deep tech startups must clearly demonstrate to them the strategic and market potential of this type of innovation and the use of technologies and science in frugal innovations.

Investors in deep tech startups are advised to pay attention to the competitive advantage that these companies, based on science and technology, develop solutions that are difficult to imitate, creating entry barriers for competitors. It is important to remember that difficulty in imitation is one of the factors related to business success.

For public policy makers in science, technology, and innovation in emerging countries, considering the potential positive impacts of the innovations to be generated by deep tech startups, it is appropriate to act on bottlenecks, through fostering actions combining public and private resources, such as blended finance mechanisms (De la Tour et al., 2021; Nedayvoda et al., 2021), associating compensations for the private investor to act in operations with high levels of uncertainties and risks; and large needs for financial resources and time compared to other startups. Additionally, since businesses based on frugal innovations have the potential to present an effective response to the external constraints of income and infrastructure present in emerging economies and are still opportunities not yet fully explored by investors, it is appropriate to develop lines supporting explicitly businesses with such characteristics.

CONCLUSION

The guiding question for this research was: "What is the role played by technological capabilities and frugal innovation capacity in attracting investments in deep tech startups located in emerging economies?" Following the Resource-Based View (RBV) perspective, in emerging markets, technological capability attracts private investors, regardless of the imitability attribute. However, although frugal innovation capacity is relevant for the development of difficult-to-imitate innovations in deep tech startups, it is not significant in attracting investments. Therefore, the technological complexity for the development of advanced frugal innovations may be difficult for investors to understand due to the unconventional nature of the solutions, lack of market references, and specificities of emerging economies. Thus, it is essential for entrepreneurs working in this field to strive to clearly communicate the value proposition and viability of their frugal solutions, in order to overcome these difficulties and attract investments.

This study has some limitations and suggests possible directions for future research. Firstly, the questionnaire was developed using binary variables, not allowing for the identification of the intensity of the CEOs' responses. Therefore, it would be important to consider the use of other types of scales, such as Likert scales, which allow for greater expressiveness in participants' responses. Secondly, the research only adopts digital technologies to measure technological capabilities. Combining different types of technologies, such as biotechnology and nanotechnology, could provide a more comprehensive understanding of the role of technological capabilities in attracting investments. Thirdly, there was no specific analysis by sector. However, the health sector, for example, has unique characteristics, such as regulations, clinical requirements, ethical and privacy considerations, among others, which would justify dedicated research to this sector. Additionally, it is important to note that the sample of this study was limited to the state of São Paulo. A possible approach for expansion would be the inclusion of deep tech startups from diverse geographical contexts. Finally, future studies could explore the association between frugal innovation and effectuation. In this article, we examine the issue of frugal innovation and its association with non-imitation and investment reception. However, we believe that the process by which frugal innovation reaches the point of non-imitation is significantly influenced by aspects of effectuation, which could be elucidated through qualitative research. Similarly, the association of how this investment reaches the company is closely related to effectual thinking, particularly in companies oriented towards frugality.

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Conflict of interest statement

The authors declare that there is no conflict of interest.

Authors' statement of individual contributions

Roles	Contributions				
	Diógenes K. C. A.	Martins A. C. C. L.	Pavani C.	Borini F. M.	Plonski G. A.
Conceptualization	■	■	■	■	■
Methodology	■	■	■	■	■
Software	■				
Validation				■	■
Formal analysis	■	■	■	■	■
Investigation	■	■	■		
Resources	■	■	■		■
Data Curation	■				
Writing - Original Draf	■				
Writing - Review & Editing	■	■	■		
Visualization	■				
Supervision				■	■
Project administration					■
Funding acquisition	N. A.				

Note: Acc. CRediT (Contributor Roles Taxonomy): https://credit.niso.org/

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