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FORESIGHT AND STI GOVERNANCE 15 years

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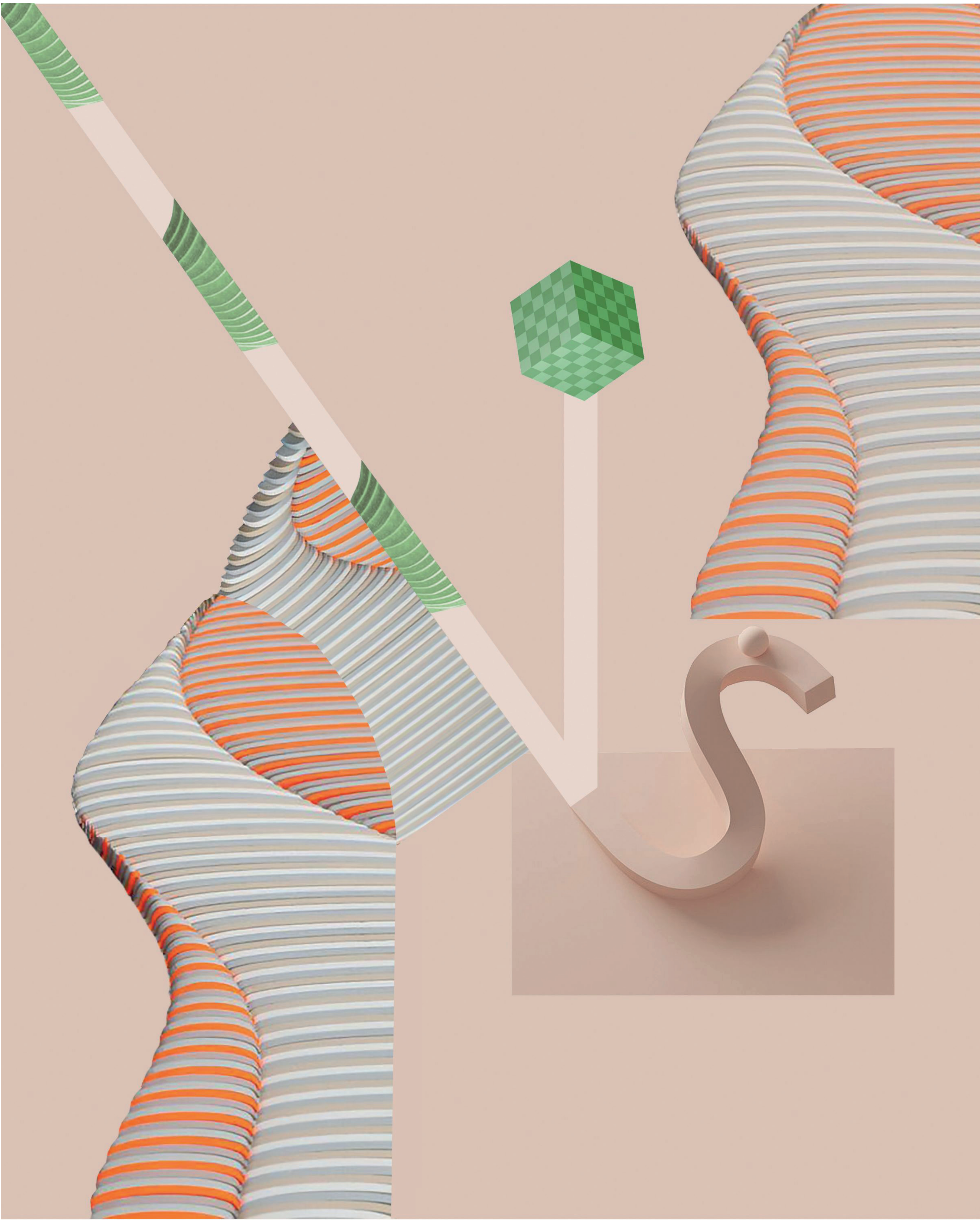

Relocation as a Driver of Innovative Activity: A Global Study of Unicorn Founders' Migration

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Abstract

This paper investigates the migration flows of unicorns – private companies that achieve a market value of at least one billion USD within ten years. This concept was recently introduced by professional investors but has actively entered the global expert and political agenda. The ability of national innovation systems to grow unicorns has become a new hallmark of success.

This study uses the most complete sample of companies as of July 2022 (1,357 unicorns), for each of them we identified the founders, their countries of birth, and the educational institutions they graduated from.

Among the main results, it is revealed that 40% of billion-dollar companies were created with the participation of foreign founders. The authors identified three country groups depending on the founders' migration flows direction: "attracting" unicorns, "growing on their own" and "losing everything". A comparative analysis of countries' innovation profiles made it possible to identify the unicorn growth and attraction factors. It is emphasized that universities are a significant resource for both strategies, since most of the founders graduated from the leading world universities and every third foreign entrepreneur was educated in the country of migration. It is shown that the strategy of attracting foreign founders complements the growth strategy and could provide the main flow of unicorn founders. The authors noted that the leading unicorn countries are actively involved in the global migration flow: they not only attract the founders, but also act as their largest suppliers. The authors put forward recommendations for attracting unicorn companies.

Keywords: fast-growing companies; gazelles; scaleups; unicorn companies; unicorn companies' migration; unicorn companies attracting policy

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Introduction

Over the past decade, the number of rapidly growing technology start-ups with a high market capitalization has significantly increased, and their geography has markedly expanded.[1] A special place among them are held by "unicorns": companies whose capitalization has reached one billion USD within ten years of their establishment, while they remained at least three-quarters owned by the original founders and did not make an initial public offering (IPO) (Lee, 2013; Crunchbase, 2022).

High-tech and fast-growing companies have been central to the political agenda and academic discourse in recent years due to their ability to influence the emergence of new industries and create favorable economic and social effects (Baumol, Strom, 2007; Guerrero, Urbano, 2019; Audretsch et al., 2020 ; Autio et al., 2014; Brown, Wiles 2015; Bock, Hackober, 2020). The Organisation for Economic Co-operation and Development (OECD) estimates that about 5% of small and medium-sized fast-growing companies create more than half of new jobs (OECD, 2021). The recognition of these players' contribution to economic growth has contributed to the emergence of a wide range of strategic initiatives the world over, and was reflected in various programs such as Europe 2020,[2] 2030 Digital Compass: the European Way for the Digital Decade,[3] France 2030,[4] and in OECD reports on international business policy,[5] etc. Moreover, some of the initiatives are directly aimed at raising unicorns (e.g., Scale up 100[6] or Baby Unicorn 200 Nurturing Project[7]).

Unicorns and their phenomenal growth attracted a lot of attention from the press, investors, experts, and politicians, but the topic remains insufficiently studied in academic literature. Despite the many publications on the migration of highly skilled professionals and entrepreneurs (Anderson, Platzer, 2006; Chaloff, Lemaître, 2009; Fairlie, Lofstrom, 2014; Blume-Kohout, 2016; etc.), the studies on unicorn migration remain extremely limited, fragmentary (Testa et al., 2022; Anderson, 2022), and incomplete: the sample of one of them included 582 companies established in the United States (Anderson, 2022), while another analyzed 40 unicorn firms which have migrated from the EU (Testa et al., 2022). The focus tends to be on unicorn growth factors, typically based on data for specific countries (Simon, 2016; Bhagavatula et al., 2019), while unicorn founders' global migration flows remain unaddressed. We are not aware of any academic publications offering a systemic analysis of the factors that help attract foreign unicorn founders.

Unlike previously published studies, ours is based on a full global sample of 1,357 unicorns (as of July 2022) and considers the migration flows of these companies' founders (3,190 people) covering all their countries of origin. Unicorn "exporter" and "importer" countries were compared by key development indicators. Open-access information on the universities where the 2,699 unicorn founders were educated was used.

The purpose of the paper is to comprehensively analyze the migration flows of unicorn founders. To achieve it, the following questions were consecutively answered:

1. What were immigrants' contributions to the establishment of unicorn companies compared to those of natives?
2. Is there any correlation between the unicorn company's market value and the presence of an immigrant among its founders?
3. Which countries are the largest exporters of unicorn founders?
4. Which countries are particularly attractive to migrating unicorn founders?
5. Which countries have a nationally diverse composition of foreign unicorn founders, and which ones are dominated by specific diasporas?
6. What are the specific characteristics of countries that attract unicorns? Which country factors attract such companies and promote their creation?
7. Which universities attract foreign unicorn founders and which are their biggest exporters?

Literature Review

The Phenomenon of Rapidly Growing Companies and the Unicorn Concept

Interest in studying enterprises with high growth potential arose in the late 1980s. To describe fast-growing companies, the US economist David Birch suggested the concept of "gazelles". He defined them as firms whose workforce grew on average by more than 20% a year over a three-year period, with the initial number of staff being at least 10 (Birch, 1987). Like the corresponding antelope species, such companies could achieve a high growth rate quickly and maintain it over long distances. Having analyzed data on company and employment growth in the United States in 1969-1976, Birch found that two-thirds of jobs were created by small companies with fewer than 20 employees.

While Birch's research has attracted the attention of academics, international organizations, and governments (Coad et al., 2014; Petersen, Ahmad, 2007; Acs et al., 2008), the debates about the reliability

[1] https://www.cbinsights.com/research-unicorn-companies, accessed on 04.10.2022.

[2] https://ec.europa.eu/eu2020/pdf/COMPLET%20EN%20BARROSO%20%20%20007%20-%20Europe%202020%20-%20EN%20version.pdf, accessed on 04.10.2022.

[3] https://eur-lex.europa.eu/resource.html?uri=cellar:12e835e2-81af-11eb-9ac9-01aa75ed71a1.0001.02/DOC_1&format= PDF, accessed on 04.10.2022.

[4] https://www.economie.gouv.fr/files/files/2021/France-2030.pdf?v=1641479311, accessed on 04.10.2022.

[5] https://doi.org/10.1787/9789264048782-en, accessed on 04.10.2022.

of criteria for identifying high-growth companies continued (Stone, Badawy, 2011; Haltiwanger et al., 2010; Coad et al., 2014). The OECD and the Statistical Office of the European Union (Eurostat) consider gazelles as a variety of rapidly growing companies in accordance with the growth criteria originally proposed and validated by other researchers, limiting their age to five years (Ahmad, 2008; Petersen, Ahmad, 2007; OECD/Eurostat, 2008). Company growth is measured both in terms of the number of employees and revenues.

Another type of rapidly growing firm is represented by "scale-ups": dynamic companies established no more than 10 years ago which have attracted funding of at least 1 million euros in total.[8] Some authors consider the concepts of scale-ups and gazelles as synonymous (Seip et al., 2022). Studying them is complicated by the fact that small private companies rarely disclose data on their growth (Petersen, Ahmad, 2007) and funding.

The range of concepts describing various aspects of fast-growing businesses also includes "hidden champions": these were originally conceptualized by Herman Simon (Simon, 1990) as companies little known to a wide range of consumers, dominating narrow market segments (number one at the national level, or one of the top three in the world), with a relatively small workforce,[9] and revenues up to 4 billion USD.[10] Such niche leaders favor incremental sustainable innovation over disruptive radical innovation strategies (Simon, 1996; Yoon, 2013) and make a significant contribution to national exports (Fryges, 2006; Kim, Suh, 2015). However, their activities tend to remain in the shadows, which makes it difficult to identify them, while the low recognition criterion itself is hard to formalize (Simon, 1996; Schenkenhofer, 2022).

The "national champions" idea (Maincent and Navarro, 2006; Aubert et al., 2011), which gained wide popularity among politicians, originated in France and proliferated throughout the world. However, unlike the fast-growing company types considered above, criteria for identifying national champions are less clear. There is no consensus on whether this concept applies exclusively to the largest of, or all particularly successful companies regardless of their size, and whether their competitiveness in strategic industries should be taken into account (Maincent, Navarro, 2006). Many researchers include in the number of national (sometimes also called "industry") champions the largest medium- and high-tech corporations in the country (Maincent, Navarro, 2006), which act as agents of strategic national interests on the world market and enjoy state protection (Aubert et al., 2011; Melnik, 2019).

The idea of nurturing national champions was embraced by China's industrial policy, officially announced by the government in the late 1990s. (Poon, 2009). By now China has gained significant experience in this area,[11] among other things through the use of protectionist measures (Hemphill, White, 2013). The country has adopted a high-technology enterprise certification system and now maintains a register of those. Companies that have confirmed their status become more visible for the government and investors, thus increasing their access to tax incentives and other state support measures, and strengthening reputational advantages. At the same time the state's active involvement in promoting national champions has been criticized for interfering with open competition (Simon, 1996; Hemphill, White 2013; Melnik, 2019). It has been proposed to shift the emphasis of support policy from national leaders to small rapidly growing high-technology firms (Maincent, Navarro, 2006).

In this context, the venture investor Aileen Lee published a paper about technology companies which have reached an estimated market value of 1 billion USD and the author called these firms "unicorns" (Lee, 2013). The concept reflected the unique, or very rare nature of an event such as the birth of a billion-dollar company, and since then became firmly established in the professional and academic discourse (Brown, Wiles, 2015; Jinzhi, Carrick, 2019; Bock, Hackober, 2020).

Unicorns are increasingly conquering the world's high-tech markets, but remain quite rare: just one in a hundred companies which have received seed capital becomes a unicorn.[12] In 2013, when this concept emerged, the opportunities to join the club were much more limited: according to one estimate, only six out of a hundred thousand start-ups reached unicorn status.[13] And though the 1 billion USD threshold was rather arbitrary, it has become a kind of psychological marker for investors, entrepreneurs, and the press,[14] and a benchmark for the public sector (Simon, 2016; Testa et al., 2022). Plus, given the non-public nature of

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[6] https://eic.ec.europa.eu/news/european-innovation-council-launches-scale-100-call-2022-05-16_en, accessed on 04.10.2022.

[7] www.k-unicorn.or.kr and https://www.mss.go.kr/site/smba/main.do, accessed on 04.10.2022.

[8] https://www.eur.nl/media/100543, accessed on 04.10.2022.

[9] On average 2,000 people, which is 33 times lower than the figure for Fortune Global 500 companies in 2007 (Simon, 1990, 1996).

[10] As examples of hidden champions, Simon names Technogym (world leader in distributing fitness, sports, and health equipment and digital technologies, originally from the Italian village of Gambetolla), Zimmer, DePuy, Biomet (global leaders in orthopedic implants production, originally from the small city of Warsaw, Indiana (USA), the informal world orthopedic capital), Plansee (flagship in production of high-quality materials from refractory metals and composites, based in the Austrian city of Reutte), SAP (leader in developing business software located in the Germany's Walldorf), etc.

[11] The BATX companies (Baidu, Alibaba, Tencent, Xiaomi) are examples of Chinese technology leaders.

[12] https://2020.stateofeuropeantech.com/chapter/state-european-tech-2020/, accessed on 04.10.2022.

[13] https://review.firstround.com/Theres-a-00006-Chance-of-Building-a-Billion-Dollar-Company-How-This-Man-Did-It?utm_source=salesforce&utm_medium=blog, accessed on 04.10.2022.

[14] http://fortune.com/2015/01/22/the-age-of-unicorns/, accessed on 04.10.2022.

these companies, the proposed criteria turned out to be clear and apprehensible, and are now actively used by analytical platforms (such as, e.g., Crunchbase,[15] CB Insights,[16] Dealroom,[17] or Pitchbook[18]).

The key difference between unicorns and other company types considered above is that the former's success is based on venture capitalists' support and their capitalization is estimated on the basis of investments received (which reflect the predicted growth potential, but is not always supported by actual financial performance indicators). Some companies were evaluated by investors at many billions despite them posting major losses[19] (e.g. Uber[20] or Snapchat[21]). Rapid user acquisition rates and offering unique products and services often turned out to be the critical factors here.

On the contrary, scale-ups, gazelles, national or hidden champions do not rely on professional investors' assessments. Their capitalization is based on the actual dynamics of financial indicators, and the number of jobs created. Hidden champions, unlike unicorns which are focused on business scaling and global reach, prosper in narrow market segments. In turn, national champions are the established leaders who operate in strategic government-supported industries. Being radical innovators, unicorns create new industries pushing mature corporations out, including in manufacturing (Bock, Hackober, 2020). Some researchers define this displacement process as "creative destruction" (Simon, 2016).

Unlike most gazelles, many scale-ups, and some national champions, unicorns' success is based not on the little-informative reports of non-public companies (which tend to be incompatible for international comparison), but on independent assessments by professional investors who have risked their money. This is the key advantage of the unicorn concept, which has made it popular among experts, politicians, and investors.

Unicorns are gradually becoming a symbol of entrepreneurial ecosystems' success, which increases the interest in studying the context of their operations and the many observable and hidden growth factors. A European Commission study (Testa et al., 2022) identified key growth predictors for 1,659 former and current unicorns in 53 countries: the use of high technologies, access to venture capital, high-quality education, and the entrepreneurial experience of their founders. These results confirmed the key findings of a previous European Commission study (Simon, 2016) based on a smaller sample of 23 unicorns.

Researchers from the University of Nottingham have studied the impact of universities on technology entrepreneurship (Ratsinger et al., 2018). On the basis of data about 4,953 digital start-ups, they found that companies' success and chances to attract investments largely depend on the level of the entrepreneurs' education. The role of universities in unicorns' fate is even more obvious. Almost all unicorn founders have a bachelor's degree, about half of them have a master's or an MBA, and about 12% have a PhD (Testa et al., 2022). The effect of a high-quality university education on raising unicorns can also be traced at the level of individual countries. For example, among the founders of South Korean unicorns, a group of young entrepreneurs - graduates of the Korea Advanced Institute of Science and Technology - stand out, one of the most innovative in the country and a leading university of the world (Seoul Business Agency, 2019).

The rapid growth of unicorns was facilitated by the development of mobile internet and relevant applications, the increased availability of software, digital platforms, cloud computing, and business models based on them (Kenney, Zysman, 2019; Bock, Hackober, 2020). The key aspects of unicorn companies' operations include high business scalability and rapid growth (which investors see as indirect indicators of their value) (Kenney, Zysman, 2019; Bock, Hackober, 2020), and increased user coverage, involvement, and retention. Most of these fast-growing companies specialize in software development, AI, cybersecurity, and biotech (Anderson, 2022).

On average, companies in the EU reach unicorn status at the age of ten years (to compare, in the US and China this figure is eight and five years, respectively) (Testa et al., 2022). Between 2008 and the second quarter of 2021, venture capitalists in the EU invested an average of 125 million euros in a unicorn (in the US - 138 million euros, in China - 204 million euros) (Testa et al., 2022). The larger venture investments in the US and China help start-ups attract more funding and reach the billion-dollar mark faster than "Europeans" do. In addition to the size of the venture capital market, the higher speed of achieving unicorn status in China is also due to corporations' (such as Tencent, Alibaba, Huawei, ZTE) targeted efforts to raise new technology leaders (Jinzhi, Carrick, 2019).

Despite their youth, unicorns are able to compete not only with mature corporations, but with entire industries, and even economies. For example, the total capitalization of all US unicorns exceeds 2 trillion USD, i.e., the value of all companies listed on major stock

[15] https://news.crunchbase.com/unicorn-company-list, accessed on 04.10.2022.

[16] https://www.cbinsights.com/research-unicorn-companies, accessed on 04.10.2022.

[17] https://app.dealroom.co/unicorns, accessed on 04.10.2022.

[18] https://pitchbook.com/news/articles/unicorn-startups-list-trends, accessed on 04.10.2022.

[19] https://hbr.org/2018/02/why-financial-statements-dont-work-for-digital-companies, accessed on 28.10.2022.

[20] https://news.crunchbase.com/startups/understanding-uber-loses-money/, accessed on 28.10.2022.

[21] https://www.theguardian.com/technology/2017/mar/02/snapchat-ipo-valuation-evan-spiegel-bobby-murphy-snap-inc, accessed on 28.10.2022.

exchanges in countries such as Argentina, Colombia, Peru, Portugal, Ireland, Russia, etc. (Anderson, 2022). These exceptional results are driving countries into a global race for potential unicorns, and for finding ways to make national entrepreneurial ecosystems more attractive.

The Role of Foreign Talent and Factors Affecting International Unicorn Migration

According to one of the many approaches to studying the reasons for the spatial concentration of economic activities, resources, and production (Porter, 1990; Krugman, 1991), it is driven by the desire to share ideas and gain access to local knowledge and lucrative business contacts (Jaffe et al., 1993; Audretsch, Feldman, 2004; Arzaghi, Henderson, 2008). The level of high-tech companies' concentration and entrepreneurial migration depend on the availability of capital and the proximity to cutting-edge scientific achievements, universities, and talent clusters (Calcagnini et al., 2016; Kerr, 2020). Migration promotes further growth of entrepreneurial and innovation activity (Fairlie, Lofstrom, 2014; Blume-Kohout, 2016; Brown et al., 2019; Anderson, 2022) as an object of interest of national authorities, international organizations, and a wide range of researchers (CCG, 2017; Cerna, 2016; Chaloff, Lemaître, 2009; Clemens, 2011).

According to certain estimates, immigrant inventors' contribution to patent activity is higher than that of natives (Kerr, Kerr, 2020b). The most active innovators (with more than 200 registered patents to their credit) emigrate five times more often than their less productive colleagues, thus positively affecting innovation activity in their places of relocation (Akcigit et al., 2016; Zacchia, 2018). One of the most mobile talent pools turns out to be Nobel Prize winners: a third of them work outside their country of origin (Kerr, 2020). Approximately 70% of software engineers in Silicon Valley were born outside the US (Kerr et al., 2016).

Due to immigrants' higher level of business activity (Borjas, 1995; Fairlie, 2012), politicians in many countries see them as a resource for increasing the number of potential entrepreneurs (Kerr, Kerr, 2020a). Immigration is believed to serve as a screening mechanism for people with a greater propensity to take risks (Kerr, 2019). They are more likely to create companies in high-technology sectors than in low-tech ones, more inclined (compared to the natives) to choose STEM (Science, Technology, Engineering, and Mathematics) as their specialization area (Hunt, 2015; Hanson, Liu, 2018; Kerr, Kerr, 2020a), and are more actively involved in research and development (R&D) (Brown et al., 2019; Kerr, Kerr, 2020a). Thus, unsurprisingly, about 40% of the world's Fortune 500 companies which generate the largest revenues were founded by first- or second-generation immigrants (Partnership for a New American Economy, 2011).

The migration of unicorns and of their founders is of particular interest (Simon, 2016). Its geography is determined by factors such as the availability of capital, expertise of universities and R&D centers, the presence of a fruitful, knowledge-intensive environment, access to broadband mobile communications, favorable tax regimes, and innovative infrastructure (Simon, 2016; Guerrero et al., 2019; Testa et al., 2022). Venture capital plays an important role in the level of unicorns' concentration (Testa et al., 2022). This is expressed, in particular, in the way experienced investors select companies with a high growth potential (Bengtsson, Wang, 2010; Achleitner et al., 2013). Start-ups are much more likely to succeed when they have access to expertise and business acumen of highly qualified venture capital investors (Alperovych, Hübner, 2013; Bernstein et al., 2016; Breuer, Pinkwart, 2018). Their reputation promotes the growth of asset portfolio value by reducing information asymmetry between participants (Lee et al., 2011; Achleitner et al., 2013; Hsu, 2004). Meanwhile established investors themselves become even more visible and gain an informational advantage in spotting investment opportunities by attracting additional resources for portfolio companies (Krishnan et al., 2011; Bock, Hackober, 2020). In turn, entrepreneurs are willing to accept a lower valuation of their company to gain access to large investors' capital, anticipating future reputational and financial benefits from such transactions (Hsu, 2004).

Rapidly growing companies seek to benefit from developed entrepreneurial ecosystems (Guerrero et al., 2021) by moving to metropolitan areas with a high concentration of resources. For example, relocating to the San Francisco Bay Area facilitates access to resources, leads to productivity growth by attracting venture capital (3.5 times in six years), increased patent activity (4.7 times), increased sales, and IPO placement (Guzman, 2019). The United States' special position on the global market has led to the emergence of a kind of psychological pattern, when the very move to this country is perceived as increasing technology entrepreneurs' chances for a gainful career.

Data and Methodology

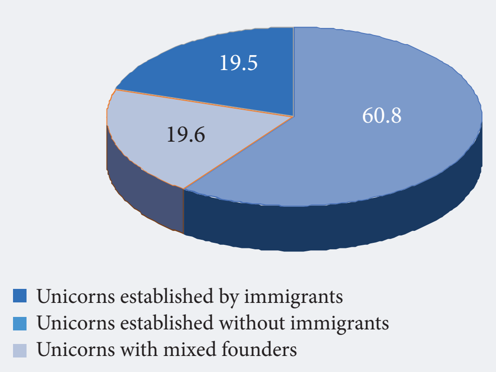
The source of data on unicorn companies used in this study was the largest international platform Crunchbase, which aggregates information about start-ups, investors, and venture deals. As of July 2022, there were 1,357 unicorns in the world registered in 49 countries. Over the course of the study, information on estimated value was collected for each of them: for 1,329 companies (98%), the amount of venture investments they received was determined; and for 1,320 a list of 3,190 entrepreneurs who participated in the establishment of the original start-ups and acted as their ideological architects was compiled. Such a striking mismatch between the number of unicorns and the number of their founders is due, among other things, to the fact that some companies were founded by 10 or more people: 19 in the case of Lazada Group, 12 for Starburst, and 10 for Oda. On the other hand, the same person could establish several unicorns, e.g., Liu Qiangdong established JD Digits, JD MRO, and JD.ID, or Sebastian Thrun, who founded Cresta, Udacity, and Waymo.

During this study, based on open data available on the internet, all unicorn founders' countries of birth and higher education were determined. The main data sources were their social network profiles and personal websites. The secondary source was unicorn companies' websites, news about them, and interviews with their founders. The country of birth was determined for all 3,190 entrepreneurs, while data on higher education was found for 2,699 of them (84.6%).

Migration flows were traced by comparing unicorn founders' countries of birth with the places of their companies' registration. Depending on migration paths, countries were broken down into three groups: those pulling unicorns in from outside, raising their own, and losing them all. Table 1 presents the typical members of each group and the selection criteria (chosen in such a way as to exclude countries with a small number of unicorns: 11 nations have a single unicorn company, five have two, and six have three). Otherwise, the presence of a foreign founder in one or more unicorns would result in high internationalization values that are unrepresentative in terms of countries' actual appeal.

A systemic approach was applied to analyzing unicorn raising and attraction factors: countries in all of the above groups were compared by such criteria as wellbeing, smart money supply, technological development, institutional conditions, and education and science (Table 2). After collecting the relevant data, the most significant differences between the three country groups were identified. Countries where unicorn founders were educated and where the unicorns were registered were compared separately to determine the role of universities in founders' migration and identify more productive universities in terms of the number of graduates who have subsequently created a unicorn company.

Figure 1. **Breakdown of Unicorn Companies by Founders' Nationality** (%)



Source: authors.

Analysis of Unicorn Founders' Migration Flows

Differences in foreign- and native-founded unicorns' capitalization

A total of 979 of the 3,190 unicorn founders analyzed (30.5%) migrated to another country and created a unicorn there, indicating the high mobility of such entrepreneurs: almost nine times the migration rate for the general population (McAuliffe, Triandafyllidou, 2021), three times for inventors, and comparable to one of the most mobile talent groups, Nobel laureates (Kerr, 2020). In total, immigrants created 517 billion-dollar start-ups (39.3% of the total number of unicorns whose founders are known), 258 were established exclusively by immigrants, and 259 were of "hybrid" origin (i.e., had at least one native founder) (Figure 1).

The total estimated value of the unicorns analyzed in the course of the study was 4.6 trillion USD, half of which (2.3 trillion) is made up by companies with foreign founders.[22] Collectively, unicorn companies raised 833.9 billion USD in venture capital investments, 37.5% of that sum was raised by unicorns with a migrant founder.[23]

Companies established by foreigners (exclusively, or jointly with natives) and without them show very similar investment performance (Figure 2). Unicorns created by migrants attract almost the same amount of venture capital as those established solely by natives, but on average are valued 1.2 times higher. The discrepancy between the mean and median values indicates that the most valuable unicorns tend to have foreign founders. If seven of the 10 top-value unicorns have foreign founders, for the top 100, the ratio becomes almost equal: 49 companies do have a foreign founder and 51 do not.

Foreign unicorn founders' nationality and the countries to which they relocate

To analyze unicorn founders' migration, the countries of these entrepreneurs' origin (on the left in Figure 3) were compared with countries where they have chosen

[22] Only three of the 10 top-value unicorns do not have foreign founders: ByteDance internet company (180 billion USD, the highest value among all unicorns); Ant Group payment platform (150 billion USD, 2nd place); and Canva graphic design services (40 billion USD, 7th place). The most valuable foreign-founded billion-dollar startup is SpaceX (125 billion USD, 3rd highest value), followed by the fashion retailer Shein (100 billion USD, 4th place), and the US fintech startup Stripe (95 billion USD, 5th place).

[23] Half of the top 10 companies by the amount of raised capital have a foreign founder (e.g., JULL with 15.1 billion USD, SpaceX with 9.5 billion USD, Northvolt with 7.0 billion USD), while the other half do not (Ant Group with 22 billion USD, Cruise with 15.1 billion USD, and ByteDance with 9.4 billion USD).

Table 1. **Groups of Countries by the Direction of Unicorn Founders' Migration Flows**

Country group	Group basis	Membership criteria	Typical representatives
Pulling unicorns in from outside	Attraction factors	Country must have at least seven unicorns, over 50% of which were founded by migrants	USA, UK, Germany, Canada, Singapore, Switzerland, Mexico, Indonesia
Raising their own unicorns	Raising factors	Same number of unicorns as in the previous group, but less than 30% of them founded by migrants	China, India, France, Israel, South Korea, Australia, Japan, Sweden
Losing all	"Hygienic" factors* whose low level prompts unicorn founders to leave	No unicorns, but more than eight founders were born in the country	Russia, Romania, Poland, Bulgaria, Pakistan, Ukraine, Iran

* This term is explained later on in the paper.
Source: authors.

to register their companies (on the right). A total of 979 entrepreneurs from 85 countries were identified in the course of the study, mostly from Israel (151 people or 15.4% of all migrant unicorn founders in the world), India (145 or 14.8%), China (63 or 6.4%), the United States (50 or 5.1%), and the UK (46 or 4.7%). Together, these countries account for almost half (46.5%) of all migrant unicorn founders. From 38 countries, two or fewer unicorn founders emigrated; together, they account for 5.6% of the total number of entrepreneurs under consideration (among them are Indonesia, Japan, Finland, and Malaysia). As shown in Figure 3 on the right, the number of countries attractive to unicorn founders is three times smaller (32). The largest numbers have relocated to the US (690 or 71.4%), UK (55 or 5.7%), Singapore (49 or 5.1%), Canada (28 or 2.9%), and China (23 or 2.4%).[24]

Unicorn importer countries are deeply integrated into global migration flows: they not only attract foreign entrepreneurs, but also offer their own to the world. On the other hand, countries that only raise unicorns at home, or only pull them in from outside are relatively rare. Examples include the UAE and Ecuador: not a single unicorn founder has left them, but seven have moved in.

The group of "net" unicorn founder importers comprises 55 countries, which together account for a quarter (25.7%) of all migrant entrepreneurs. In this cohort, the largest numbers of unicorn founders come from Russia (38 people or 3.9%), Ukraine (20 or 2%), Argentina (13 or 1.3%), Portugal (13 or 1.3%), South Korea (12 or 1.2%), Romania and Iran (11 each or 1.1%), and Poland (10 or 1%).

The top 10 countries by number of unicorns located on their territory have different shares of such companies founded by migrants (Table 3). For example, South Korea has none at all, while in Singapore their share reaches 83.3%.[25]

Thus, the number of unicorns in the country does not always depend upon its appeal to founders, since the list of top unicorn hosts includes countries with a high share of foreign entrepreneurs (Singapore), and with none at all (South Korea). The top five such nations are just as heterogeneous in this regard: 50-55% in the US, UK, and Germany, and 8.0% and 4.2% in China and India, respectively.

The United States is the most diverse country in terms of migrants' origins: unicorn founders from 73 countries have relocated there. In Singapore, billion-dollar start-ups were founded by people from 22 countries, in the UK from 21, in Germany from 15, and in China from 13. An analysis of migrant entrepreneurs' nationalities in countries with their highest concentration revealed the prevalence of several donor nations in the total flow (Figure 4).

Despite the fact that the United States has the highest national diversity of incoming entrepreneurs, it is difficult to single out a clear leader in the total migrant flow: Israel and India account for approximately equal shares, at 19% and 18%, respectively. Immigrants from Israel dominate in the UK, at 22%. Entrepreneurs of Indian origin make up the bulk of immigrants in Singapore, at 20%. The main supplier of unicorn founders to Canada and China is the US, at 32% and 48%, respectively.

Innovation profiles of countries which raise, attract, and lose unicorn companies

Countries that have raised unicorn founders differ in terms of the prevalence of native vs. foreign entrepreneurs in this group. Some countries "exported" all their unicorns and could not attract any from abroad. The first two groups of countries presented in Table 1 above succeeded in both pulling unicorns in from outside and raising their own: 846 (62.3%) of all unicorns in the world were established by founders migrating from abroad, while 412 (30.4%) were founded by native entrepreneurs; together, these 16 countries host 92.7% of all unicorns in the world. On the contrary, the third group does not have a

[24] Seven countries were identified (Turkey, Nigeria, Austria, Thailand, Finland, Malaysia, and Lithuania) to each of which relocated a single unicorn founder, and 17 more which became home to between one and ten unicorn founders: nine in Brazil, eight each in Mexico and Indonesia, seven in Belgium, five in the Netherlands, etc.

[25] Countries where over half of all registered unicorns have migrant founders include Germany (51.4%), Canada (52%), UK (52.7%), and US (54.2%).

Table 2. **Indicators Applied to Assess National Economies**

No.	Indicator	Data source	Period
1. Wellbeing			
1.1	Per capita GDP (*USD*)	World Bank [I]	2021
2. Smart money supply			
2.1	Venture investments (*billion USD*)	Crunchbase	2021
3. Technological development			
3.1	Number of largest high-tech companies	R&D Scoreboard 2500 [II]	2021
3.2	High-technology exports (%)	World Bank	2021
3.3	Gross domestic R&D expenditures as share in GDP (%)	World Bank	2021
3.4	Number of PCT applications	World Intellectual Property Organisation[III]	2021
3.5	Number of supercomputers	Top500 [IV]	2022
4. Institutional conditions			
4.1	Number of business registration procedures	World Bank	2021
4.2	International Intellectual Property Index	International Intellectual Property Alliance [V]	2021
4.3	Rule of Law Index	World Bank	2021
5. Education and science			
5.1	Number of leading universities	QS [VI], Times Higher Education [VII], and ARWU [VIII] rankings	2021
5.2	Enrolment in secondary schools (%)	World Bank	2021
5.3	Number of leading R&D organisations	Nature [IX]	2021
5.4	Number of top business schools	Financial Times [X]	2021
5.5	Number of highly cited scientists	Clarivate [XI]	2021
5.6	Number of Nobel Prize and Fields Medal winners	Official Nobel Prize[XII] and International Mathematical Union[XIII] websites	2021

[I] https://data.worldbank.org/indicator/, accessed on 14.11.2022.
[II] https://iri.jrc.ec.europa.eu/scoreboard/2021-eu-industrial-rd-investment-scoreboard, accessed on 14.11.2022.
[III] https://www.wipo.int/pct/en/, accessed on 14.11.2022.
[IV] https://www.top500.org/lists/top500/, accessed on 14.11.2022.
[V] https://www.propertyrightsalliance.org/ , accessed on 14.11.2022.
[VI] https://www.topuniversities.com/university-rankings, accessed on 14.11.2022.
[VII] https://www.timeshighereducation.com/, accessed on 14.11.2022.
[VIII] https://www.shanghairanking.com/rankings/arwu/2021, accessed on 14.11.2022.
[IX] https://www.nature.com/nature-index/news-blog/leading-research-institutions-science-nature-index-annual-tables-twenty-twenty, accessed on 14.11.2022.
[X] https://rankings.ft.com/home/masters-in-business-administration, accessed on 14.11.2022.
[XI] https://clarivate.com/, accessed on 14.11.2022.
[XII] https://www.nobelprise.org/, accessed on 14.11.2022.
[XIII] https://www.mathunion.org/, accessed on 14.11.2022.

Source: authors.

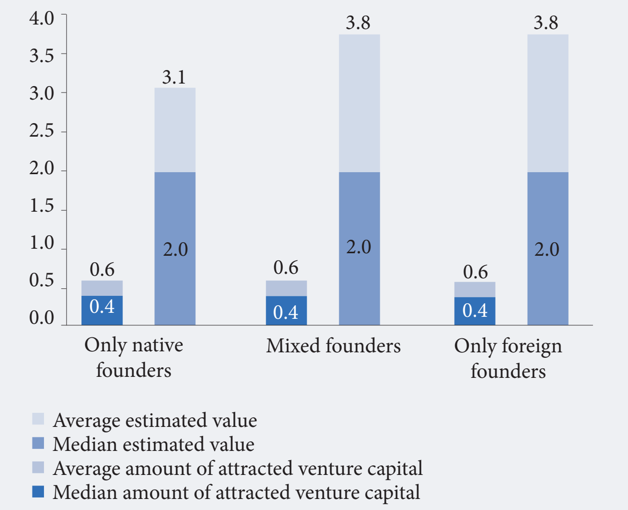
single unicorn company, but these countries have raised a large number of their future founders who subsequently created successful businesses abroad.

Comparing these country groups by indicators reflecting their wellbeing, technological development, science and education levels, and institutional conditions allows one to identify each group's typical features and estimate the importance of various unicorn attraction factors (Table 4).

Significant unicorn attraction factors include developed venture capital markets, the presence of leading universities, R&D organizations, and business schools, and of highly cited scientists recognized by the international academic community (including Nobel Prize and Fields Medal winners). Together, these factors create an attractive innovation ecosystem. As for raising unicorns, R&D expenditures seem to be more important. Countries with the highest level of such domestic expenditures are particularly successful in creating such companies on their own. Their highly productive technological environment provides a breeding ground for the emergence of unicorns.

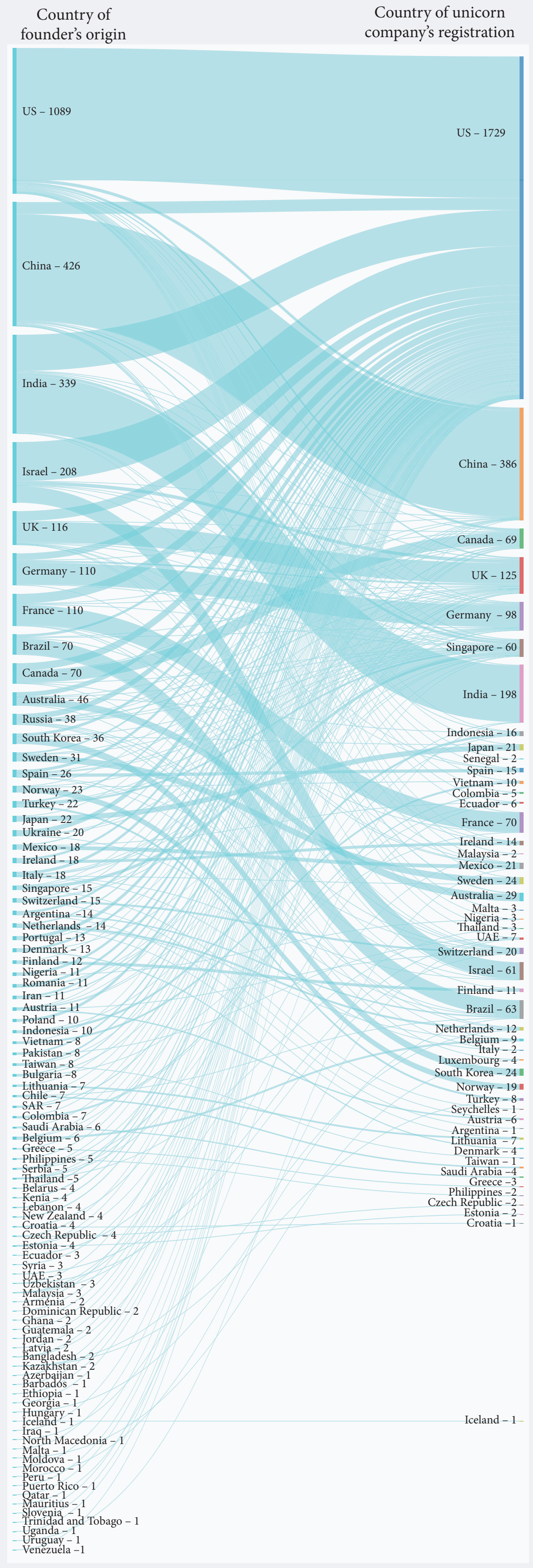
A special remark is deserved by the group of indicators whose values are similar in the countries which pull unicorns in from outside and grow their own, but much lower in those which "lose all". These factors can be called "hygienic" ones: they measure the overall health of the economy and include per capita GDP, the number of major high-technology companies, high-tech exports, international patent applications (PCT), the availability of supercomputers, intellectual property protection, and rule of law. Insufficient progress in these areas leads to the country losing potential unicorns, as it cannot get closer to the world leaders. Four out of five indicators in the Technological development section turned out to be "hygienic": unicorn founders leave countries where businesses' demand for innovations is weak, the number of manufactured world-class high-technology products is small, and IT infrastructure is backward. The same

Figure 2. **Unicorns' Value Breakdown by Founders' Nationality** (*billion USD*)



Source: authors.

Figure 3. **Global Migration Flows of Unicorn Founders, by Country** (*number of people*)



Source: authors.

applies to two out of three institutional factors which assess the legal environment.

Meanwhile there is an indicator group which does not quite fit into the precise classification of the countries presented above. It comprises company registration procedures, the number of leading universities, and enrollment in secondary education, which shows that reducing administrative barriers and providing wide access to secondary and university education remain basic conditions for obtaining competitive advantages in raising and attracting unicorns.

World's leading universities as factories of, and magnets for unicorn founders

Calculations show that universities did not remain outside the unicorn boom: the vast majority of the unicorn founders turned out to be graduates of the world's leading universities. The 20 universities that educated the largest number of unicorn founders account for almost 40% of their total number. These universities are located in just five countries: the US (13), Israel (3), the UK (2), India (1), and China (1). The most popular universities which have "produced" the largest number of unicorn founders are Stanford and Harvard, along with the Massachusetts Institute of Technology; together, they account for more than 15% of all founders[26] (Table 5).

[26] The most successful entrepreneurs: Stanford University graduates include Elon Musk (SpaceX), Adam Bowen (electronic cigarette manufacturer JUUL), and Ryan King (fintech company Chime). Harvard graduates include John Collison (fintech startup Stripe), Demet Mutlu (e-commerce platform Trendyol Group), and Omer Priel (fintech startup Rapyd). MIT alumni include Patrick Collison, brother of John Collison and co-founder of Stripe, Kyle Vogt (maker of Cruise self-driving cars), and Carlos Cashman (retail brand aggregator Thrasio). Notably, more than half of them are immigrants.

Table 3. **Number of Unicorn Companies Whose Founders Include, and Do Not Include Migrants, by Country (*units*)**

Country	Number of unicorn companies	
	No migrant founders	Migrant founders
US	308	365
China	212	17
India	71	3
UK	26	29
Germany	17	18
France	24	3
Canada	12	13
Israel	22	3
Brazil	13	6
Singapore	3	15
South Korea	18	0

Source: authors.

The average value of unicorns created by graduates of three leading universities is 1.2 times higher than that of all other billion-dollar companies (4.0 vs. 3.4 billion USD). The median value is almost the same, at 2 billion USD, which indicates the founders of the most valuable unicorns are also among these university graduates.

Universities have different appeal for foreign unicorn founders. Some universities are focused on national development, raising successful native entrepreneurs and attracting foreigners to a lesser extent. For example, those universities leading in terms of the number of unicorn founder graduates in India (Indian Institute of Technology Delhi), Israel (Tel Aviv University, Hebrew University of Jerusalem, Technion Israel Institute of Technology), and China (Tsinghua University) have less than 10% shares of foreigners in the total number of graduate unicorn founders.

On the other hand, some universities aim to attract talent from all over the world. Universities with the highest share of foreigners in the total number of graduate unicorn founders include the universities of Waterloo (about 59%), Illinois (44%), and Purdue (about 44%). Their high internationalization is evidenced by both the general heterogeneity of students' national origins (e.g. at the University of Waterloo students come from 120 countries[27]), and the highly diverse "national mix" of graduates - foreign unicorn founders (the ten such graduates of University of Waterloo come from nine countries: China, India, Russia, Romania, Lithuania, Iran, Kenya, Nigeria, and Brazil). Foreign unicorn founder graduates of the University of Illinois come from five countries, and Purdue University alumni come from four.

Universities play a major role in attracting overseas unicorn founders. Every third immigrant who created a billion-dollar company was educated in the country of their migration, most of them (about 87%) in the United States. Universities in Canada and the UK also remain attractive to them, accounting for more than 5% of foreign unicorn founders. The top 20 universities by this indicator are concentrated in the US (15), UK (3), France (1), and Canada (1) (Table 6). At the same time, the 12 universities which attracted the largest number of immigrant unicorn founders also lead in terms of the total number of foreign graduates who created unicorn companies. Some of the entrepreneurs who graduated from these universities have established billion-dollar start-ups in the country of their education, while others have chosen to do business elsewhere. The ratio of these two foreign unicorn founder groups indirectly indicates the strength of business ties and the role of the university entrepreneurial ecosystem in making the decision to open a business in the country of education or, on the contrary, the strength of the founder's old connections or the attractiveness of the business climate in other locations.

Universities particularly popular with foreign unicorn founders tend to have a significant share of graduates remaining in the country. Almost 75% of foreign graduates have created a unicorn in the country of their education, which is twice the rate for all universities where foreign entrepreneurs have studied. For immigrant Stanford University alumni (the leader

Figure 4. **Structure of Migrant Unicorn Founders' Origins in the Top 5 Host Countries (%)**

Source: authors.

Note: for each host country are shown top five countries of immigrant unicorns founders' origins.

[27] https://uwaterloo.ca/future-students/international-students, accessed on 10.10.2022.

Table 4. **Innovation Profiles of Countries Which Raise, Attract, and Lose Unicorn Companies, Based on Various Indicator Groups**

Indicator	Country group			Indicator's effect on unicorn founders' migration
	Attract from abroad	Raise their own	Loose all	
Wellbeing				
Per capita GDP (*USD*)	49 993.0	38 462.9	10 480.6	Important to retain
Smart money supply				
Venture investments (*billion USD*)	59.0	26.1	0.3	Important to attract
Technological development				
Number of major high-tech companies	137.7	138.1	0.6	Important to retain
High-technology exports (%)	20.7	19.8	7.2	Important to retain
Share of gross domestic R&D expenditure in GDP (%)	1.95	3.04	0.76	Important to raise
Number of patent applications filed under PCT	40 806.3	36 739.8	658.4	Important to retain
Number of supercomputers	12.5	15.6	1.3	Important to retain
Institutional conditions				
Number of procedures required to register a company	6.0	5.4	6.1	Irrelevant
International Intellectual Property Index	6.9	6.8	4.9	Important to retain
Rule of Law Index	1.1	1.0	-0.3	Important to retain
Education and science				
Number of leading universities	64.1	68.8	29.5	Irrelevant
Enrolment in secondary schools (%)	93.5	90.7	81.8	Irrelevant
Number of leading R&D organisations	30.7	23.2	0.7	Important to attract
Number of leading business schools	9.1	5.5	0.7	Important to attract
Number of highly cited scientists	528.9	241.0	8.1	Important to attract
Number of Nobel Prize and Fields Medal winners	35.8	5.8	1.8	Important to attract

Note: average indicator values for the country group are presented.
Source: authors.

in the "production" of foreign unicorn founders, 71 persons) this share is close to 82%. All foreign unicorn founders who graduated from the Universities of Illinois, Texas at Austin, Princeton, and Southern Californiaestablished their unicorns in the country where their alma mater was located. On the other hand, European universities tend to serve as an intermediate point along entrepreneurs' migration route. For example, none of the future billion-dollar start-up founders did this in the country of their education after graduating from the University of Oxford, or from the European Institute of Business Management. Of the University of Cambridge graduates, less than 10% of foreign unicorn founders remained in the country; for the London School of Economics and Political Science, the relevant figure is 13%, while nine out of 10 future foreign unicorn founders left Canada after graduating from the University of Waterloo.

Not only foreign unicorn founders leave after receiving a diploma; some of the future successful entrepreneurs educated in their home country also chose a more attractive one for doing business. The largest "exporters" of such graduates are Israel (115), India (97), and the US (37). But if 71% and 36% of the future unicorn founders have left the first two countries after completing their education, respectively, only about 4% left the US. Seventeen nations remain pure donors (no own unicorns) of founders, of them, Russia and Poland educated the largest number of future billion-dollar start-up creators (Figure 5).

The top five donor universities by the number of unicorn founder graduates in countries which do not have their own unicorns are the M.V. Lomonosov Moscow State University (5), Moscow Institute of Physics and Technology (4), Lisbon University Higher Technical Institute (3), and Universities of Aveiro (3), and Coimbra (3) (Table 7).

Unicorn founders' interest in the world's leading universities, combined with migration from other countries after completing their education indicate that fundamental academic training is an important, but not sufficient condition for raising unicorns. Blending the educational component with research potential creates a synergy: the best researchers and scientists attract those engaged in developing breakthrough products and services. In turn, access to large venture investors' capital helps attract and retain founders of promising technology companies.

Conclusions and Recommendations

Immigrants make a significant contribution to creating unicorn companies: about 40% of billion-dollar businesses were established with the participation of

Table 5. **Top 20 Universities by Number of Graduates – Unicorn Founders (*persons*)**

University (country)	Number of unicorn founders
Stanford University (US)	238
Harvard University (US)	143
Massachusetts Institute of Technology (US)	106
University of California Berkeley (US)	97
Indian Institute of Technology Delhi (India)	70
University of Pennsylvania (US)	64
Tel Aviv University (Israel)	51
Columbia University (US)	45
Yale University (US)	44
Tsinghua University (China)	43
Oxford University (UK)	42
Carnegie Mellon University (US)	42
New York University (US)	41
Cornell University (US)	38
Hebrew University of Jerusalem (Israel)	37
Technion – Israel Institute of Technology (Israel)	36
University of Cambridge (UK)	32
University of Southern California (US)	32
University of Washington (US)	30
Princeton University (US)	29

Source: authors.

foreign founders. Migration allows talent to choose areas with a high concentration of human, financial, and infrastructural resources, acquire local knowledge, make business contacts, and receive the best education in the world. To implement their breakthrough ideas, entrepreneurs seek to find a place (city or country) with the best combination of these factors. When talent moves into a highly productive environment, new unicorns emerge.

An analysis of countries' innovation profiles and unicorns founders' migration flows revealed that the strategy of pulling them in from outside does not contradict the strategy of raising one's own but complements it, and can even maximize the influx of such entrepreneurs. This thesis is confirmed by the examples of leading countries in the number of unicorns, primarily the United States where immigrants created more than half of all billion-dollar companies, and other nations that have succeeded in attracting them, such as Singapore (more than 80% of unicorns there have foreign founders), the UK, Canada, and Germany (over 50% in each). These findings are consistent with those of a recent study of immigrants' role in unicorn creation in the US (Anderson, 2022). Also, an analysis of a database of all active unicorns revealed a significant contribution of immigrants to the creation of billion-dollar companies. The importance of taking unicorn founders' high mobility into account in the strategies for attracting them was substantiated (more than 30% of them created a billion-dollar business outside their country of origin). The most valuable unicorns in the world have been established by international entrepreneur teams with diverse business and cultural backgrounds.

The countries that attract unicorn founders are also their largest exporters: the 32 countries to which such entrepreneurs relocated account for more than 70% of their "exports", i.e., they not only absorb the global migration flow, but also actively contribute to distributing it. Countries differ in the national diversity of incoming migrants, with some of them exchanging unicorn founders between each other: China provides 6% of the migration flow to the US (41 founders), while the US, in turn, accounts for 48% of all foreign unicorn founders in China (11 people).

Based on the prevalence of unicorns created with the participation of migrants, countries were broken down into three groups: those pulling unicorns in from outside (US, UK, Germany, etc.), raising their own (China, India, France, etc.), and losing all future founders (Russia, Ukraine, Iran, etc.). If in the first group more than half of the unicorns were established with the participation of immigrants, in the second, on the contrary, native entrepreneurs dominate. The third group has the least favorable position compared to the first two; it comprises countries that have raised founders of billion-dollar companies, but failed to either retain them or attract new ones.

The amount of venture investments is the key factor in *attracting unicorn founders*, along with the presence of high-quality science and education attributes in the country, such as leading research organizations, business schools, and highly cited scientists (including Fields Medal and Nobel Prize winners). The countries in the first group pull unicorn founders in by their research potential and outstanding scientists - top-class researchers without whom no breakthrough innovations can be created. These nations' wealth allows them to allocate significant resources for high-risk venture investments, which attracts technology entrepreneurs from other countries with more modest venture markets. The obtained results confirm other researchers' conclusions about the importance of venture capital (Bock, Hackober, 2020; Testa et al., 2022), and of founders' education for unicorn creation (Simon, 2016; Anderson, 2022), supplementing them with the thesis that the world's leading scientists and universities also play a prominent role in attracting such entrepreneurs.

Countries that *raise their own unicorns* have a high share of domestic R&D expenditures in GDP. These funds are not allocated through market mechanisms like to venture investments, aimed exclusively at making a profit and therefore insensitive to unicorn founders' origins, but through state and corporate innovation development programs primarily aimed at supporting native companies and start-ups.

Countries with low values of "hygienic" indicators find it difficult to raise unicorn creators, and even more so

Table 6. **Top 20 Universities by Number of Foreign Graduates – Unicorn Founders (*persons*)**

University (country)	Number of foreign graduates – unicorn founders	
	Total	Remainers*
Stanford University (US)	71	58
Harvard University (US)	34	23
University of California Berkeley (US)	29	26
Massachusetts Institute of Technology (US)	28	24
University of Pennsylvania (US)	19	17
Carnegie Mellon University (US)	15	11
Yale University (US)	12	10
University of Illinois (US)	11	11
University of Waterloo (Canada)	10	1
University of Texas at Austin (US)	9	9
INSEAD (France)	9	0
University of Southern California (US)	8	8
Princeton University (US)	8	8
London School of Economics and Political Science (UK)	8	3
Purdue University (US)	7	5
University of Cambridge (UK)	7	3
Cornell University (US)	6	5
Northwestern University (US)	6	5
New York University (US)	6	4
Oxford University (UK)	6	0

* Established a unicorn in the country of education. Calculations based on data on people who were educated, and created a unicorn company outside the country of birth.

Source: authors.

Some factors do not obviously affect countries' prospects for raising and attracting unicorns. Many nations make significant efforts to simplify company registration procedures, but appreciable gaps remain between them regarding property protection regimes, including intellectual property rights. The quality of education, both secondary and higher, also turned out not to be a differentiating characteristic. On the contrary, its high level promotes the emergence of successful technology entrepreneurs who may subsequently emigrate to a country with better conditions.

Unicorn founders are raised by the world's best universities. The top 20 universities by the number of graduates who have created billion-dollar start-ups account for about 40% of the total number of such businessmen. Graduates of these universities not only become successful entrepreneurs but create the most valuable unicorns: for the top three universities, Stanford, Harvard, and Massachusetts Institute of Technology, the average value of unicorns established by their graduates is 1.2 times higher than the average for all other unicorns. The role of fundamental academic training in unicorn raising is appreciable both globally and nationally, in countries where the best universities turn out to be most productive (e.g., the Indian Institute of Technology Delhi, Tsinghua University, Tel Aviv University, Oxford University, etc.).

Universities not only raise native unicorn founders, but also attract foreign ones. Some of them have a high proportion of foreigners in relation to the total number of unicorn founder graduates (e.g., about 59% for the University of Waterloo, 44% for the University

to pull them in from outside; ultimately they *lose all* potentially successful entrepreneurs due to fundamental reasons. These economies have a low level of well-being (measured as per capita GDP), which hampers effective demand for innovative products. They lack major high-tech companies which could become unicorns' partners or clients and they are insufficiently involved in global trade in high-tech products, which is expressed in low export volumes. Finally, the lack of advanced digital infrastructure (supercomputers, etc.) negatively impacts innovation and retention of talent. Our findings confirm the hypothesis suggested in the European Commission study (Simon, 2016) that the outflow of unicorns from the EU countries could have been caused by their lagging behind in the development of broadband mobile communication technologies, which is an important element of digital infrastructure. "Hygienic" indicators also include the quality of the legal environment measured by the global Rule of Law Index[28]: successful venture capitalists prefer jurisdictions with a high level of legal protection.

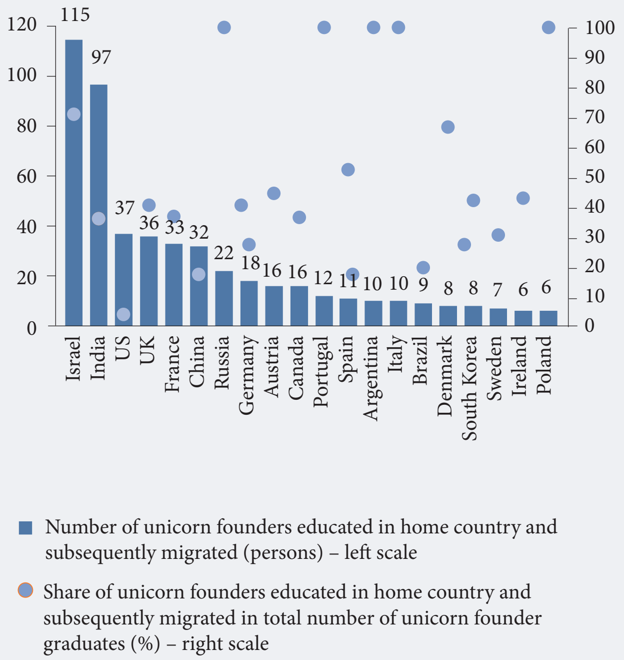
Table 7. **Donor Universities Which Have Two or More Graduates – Unicorn Founders**

University (country)	Number of graduates – unicorn founders
M.V. Lomonosov Moscow State University (Russia)	5
Moscow Institute of Physics and Technology (Russia)	4
Lisbon University Higher Technical Institute (Portugal)	3
University of Aveiro (Portugal)	3
University of Coimbra (Portugal)	3
Novosibirsk State University (Russia)	2
Wroclaw University of Technology (Poland)	2
Warsaw University (Poland)	2
University of Auckland (New Zealand)	2
Mihai Viteazul National College (Romania)	2
Belarusian State University of Informatics and Radioelectronics (Belarus)	2
University of Belgrade (Serbia)	2

Source: authors.

[28] https://worldjusticeproject.org/rule-of-law-index/, accessed on 28.10.2022.

Figure 5. **Countries from which the largest number of future unicorn founders emigrated after completing education, and their share in the total number of graduates – unicorn founders**



Source: authors.

of Illinois, and about 44% for the Purdue University), which reflects these universities' focus on global leadership.

A third of all foreign unicorn founders created their companies in the country of their education. Graduates of the top 20 universities most popular among foreign entrepreneurs establish start-ups in the country where they studied more often (at 75%) than all foreign university graduates do on average. Offering specialized educational programm, scholarships, and visas for talented foreign students, improving the international ranking of national universities, and strengthening their involvement in the international academic community helps countries use this resource to the maximum possible extent. The business contacts that foreign students - future unicorn founders establish during their studies, access to unique local knowledge, favorable research-intensive environment, the presence of outstanding scientists, and developed venture capital markets help retain those who, having completed their education, leave the country in search of more attractive conditions for doing business.

An analysis of migration flows revealed that unicorn founders tend to be quite sensitive not only to technological, but also institutional and general economic factors. At the same time "pulling in from outside" strategies require major efforts from countries wishing to direct part of the migration flow toward themselves, while "raising one's own unicorns" strategies do not fully substitute the other kind. The leading economies successfully avoid polarized approaches by raising their own unicorns, exporting them, and attracting them from abroad.

Countries which lose all, i.e., those that do not pull foreign founders in nor raise their own unicorns, find themselves in a particularly vulnerable position. This group includes Russia, which is ahead of other countries in terms of the number of unicorn founders who have left it (38 people). To move out of the outsider group, its authorities need to focus on raising their own global leaders, developing a high-technology environment, and encouraging investments in corporate R&D. At the same time, the appeal of the national entrepreneurial ecosystem for foreign unicorn founders must be increased, by promoting the development of financial markets for high-tech businesses, increasing venture capital investments, integrating universities into the international academic community, developing programs to attract foreign students, promoting science, and supporting outstanding scientists. To attract foreign technology entrepreneurs, investors, and talented professionals who want to work for promising companies, the experience of other countries that use start-up/scale-up visas can be taken into account, such as, e.g., France,[29] the UK,[30] or Canada.[31] It is important to provide comfortable institutional conditions for doing business and stay ahead of global infrastructure trends. As part of a pulling in strategy, most favored status could be introduced for highly mobile Chinese, Indian, and Israeli entrepreneurs.

Paying attention to potential unicorns, studying the factors that contribute to their emergence and relocation, and understanding how these processes can be supported are integral parts of the current innovation policy of countries striving for global technological leadership.

[29] https://lafrenchtech.com/en/how-france-helps-startups/french-tech-visa/, accessed on 03.10.2022.

[30] https://immigrationbarrister.co.uk/personal-immigration/long-term-work-visas/scale-up-visa/, accessed on 03.10.2022.

[31] https://www.canada.ca/en/immigration-refugees-citizenship/services/immigrate-canada/start-visa.html, accessed on 03.10.2022.

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Organizational Meta Capabilities in the Digital Transformation Era

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Abstract

When migrating to Industry 4.0, organizations face the need to adapt to a new context characterized by high levels of uncertainty and complexity. The main driving force in this process are the meta-competencies that ensure high competitiveness and innovativeness. However, their content, classification levels, intersections, and development potential under the influence of digitalization are insufficiently covered by the literature. This article attempts to fill this gap by analyzing the impact of new technologies on meta-competences. It presents a conceptual model based on the assumption that the degree of digitalization enhances the effects of the interaction between the top-level meta-competencies - Foresight, strategic flexibility, and ambidextrousness. Additional factors, the inclusion of which in the model will allow for a better study of the nature of the relationship under consideration, are proposed.

Keywords: Industry 4.0; dynamic capabilities; meta-competences; futures studies; strategies; digital transformation; strategic foresight; strategic agility; organizational ambidexterity

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Introduction

The fourth industrial age or Industry 4.0 symbolizes digital transformation driven by intelligent machines that communicate with one another through super-fast bandwidth connectivity. This unique ecosystem driven by advanced technologies can operate complex value chains of organizations (Sima et al., 2020). Whether in manufacturing or the service sector, business organizations around the world are unable to conduct business as usual without considering the implications of being left out of this new digital era. Organizations in many countries have already either partly or fully migrated to this unique ecosystem, while others are contemplating whether to move forward or to wait and see (Martinez-Olvera, Mora-Vargus, 2019). However, in the aftermath the COVID-19 pandemic, the migration of enterprises that were wavering in the past is now accelerating toward digitalization (Kollman et al., 2022). This realization is based on the need to deal with uncertainty by enhancing high-level organizational capabilities through greater strategic foresight, strategic agility, and organizational ambidexterity (Diego, Almodovar, 2022).

The future workplace is no longer going to be the same (Chowdhury et al., 2019), and the technologies that are considered the backbone of Industry 4.0 are becoming ubiquitous (Kraus et al., 2019). Despite the buzz created by such advanced technology-driven ecosystems, there is presently an insufficient understanding of whether such a wholesale adoption of digital technologies is going to enable organizations to enhance their capabilities to respond to a dynamic and uncertain business environment (Bal, Erkan, 2019). In the aftermath of the COVID-19 pandemic, organizational focus has been amplified with regard to developing high-level organizational capabilities such as strategic foresight, strategic agility, and organizational ambidexterity (Kumkale, 2022; Pinnsonealt, Choi, 2022). Strategic foresight has been defined as "*the ability to create and maintain a high-quality, coherent and functional forward view and use insights arising in organizationally useful ways*"), and is considered essential in developing second level meta capabilities, i.e. dynamic capabilities. The latter in turn include: seeing the risks and opportunities, seizing opportunities, and organizational transformations (Kumkale, 2022, p. 287; Rohrbeck et al., 2015). While strategic agility is considered an organization's capacity to undertake strategic long-term commitments and yet remain flexible and nimble. It is the means by which organizations reinvent and transform themselves through adaptability and ensure survival through uncertainty (Doz, 2020). Finally, organizational ambidexterity is a concept that describes two apparently contradictory processes that are undertaken in tandem, exploration and exploitation (Brix, 2020). This means that ambidextrous organizations have the ability to act in a balanced manner simultaneously in two directions: expanding their current business activities through refinement and efficiency and at the same time exploring emerging trends and phenomena as well as future opportunities without losing focus on either goal (Hirst et al., 2018).

In this regard, the digitalization of firms in Industry 4.0 is likely to be factor in driving such high-level organizational capabilities (Elgazzar et al., 2022). For instance, they have enabled seamless supply chain management through use of real-time demand data to eliminate pressure on an organization's need to build-up large quantities of inventory. Instead, the nimbleness offered by the new ecosystem enables organizations to work with smaller inventory levels by ordering more frequently based on demand. Such orders are being filled by using advanced technologies that are the backbone of the Industry 4.0 environment, such as Artificial Intelligence, Virtual Reality, Augmented Reality, Internet of Things, Cloud Computing, Big Data Analytics, 3-D Printing, Additive Manufacturing, and so on. Thus, customer orders are channeled in real-time through hyper-connected networks that distribute orders to manufacturers located worldwide. Once the product is ready, the shipment and delivery system also follow a digital stream of instructions until it reaches the customer.[1] Additional benefits relate to shorter time-to-market and order fulfillment, faster delivery, and lower transportation costs (Moeuf et al., 2018). Organizations, such as the e-commerce giant Amazon, are taking advantage of such technologies and are proactively positioning their meta capabilities that have taken productivity and efficiency to unprecedented levels (Jiminez-Zarco et al., 2019). The complex combination of new technologies within the described ecosystem provides a solid foundation for reinforcing dynamic capabilities. Organizations using machine analysis tools can process in real time large amounts of data (collected from sensors and automated devices connected to computing systems), and on that basis reconfigure production to adapt to any changes (Rosa et al., 2019; Reischauer, 2018).

As suggested earlier, digitalization is not confined to manufacturing, but in fact service organizations are rapidly considering migrating to the new ecosystem (Schmidt, Scaringella, 2020). However, new risks and challenges also form an integral part of Industry 4.0. In such a "hyper-connected" environment, new challenges arise, particularly in the area of cybersecurity. Thus, the question that remains is that whether such a migration to a more intelligent environment, where machines communicate with other devices, is enhancing organizational abilities to respond to external opportunities and threats through increased levels of strategic foresight, strategic agility, and organizational ambidexterity (Jermsittiparsert et al., 2020). Therefore, it is deemed necessary to attempt to propose a conceptual framework to better understand the links between these dimensions. In light of the preceding discourse, this study proposes a conceptual framework that suggests that digitalization moderates the relationships between strategic foresight and both strategic agility and organizational ambidexterity.

Meta Capabilities and their Classification

One of the basic concepts in strategic management, the resource-based view (RBV), poses that competitive advantage is achieved when a firm acquires resources that are valuable, rare, and inimitable by its competition, while the organization is able to exploit these qualities (Newbert, 2008). However, the limitations of the resource-based view (RBV) lie in in-

[1] https://www.forbes.com/sites/gregpetro/2020/02/17/walmart-challenges-amazon-on-sustainability/#2fdccf65bb8a, accessed 28.03.2022.

terpreting the development and re-development of resources and capabilities to address rapidly changing business environments (Bala et al., 2019). The theory of organizational capabilities serves both an extension to and an attempt to overcome the limited notion offered by RBV (Collis, 1994; Winter, 2003; Zahra et al., 2006; Ambrosini et al., 2009). It emphasizes building internal organizational capabilities (both management and technological) to respond to short-term changes rather than changing the external forces when migrating to the Industry 4.0 ecosystem (Fainshmidt et al., 2019).

Collis (1994) proposed four categories of organizational capabilities. The first "are those that reflect an ability to perform the basic functional activities of the firm." The second category concerns dynamic improvements to the activities of the firm such as continuous improvement activities. The third category is "to recognize the intrinsic value of other resources or to develop novel strategies before competitors." The fourth category is labelled "higher order" or "meta-capabilities", with the help of which organizations can change their other capabilities (Gurkan Inan G., Bititci U.S., 2015).

Organizational meta-capabilities have their own hierarchy. High-level capabilities include: 1) strategic foresight, 2) strategic agility, and 3) organizational ambidexterity (Diego, Almodovar, 2022; Kumkale, 2022; Pinnsonealt, Choi, 2022; Clauss et al., 2021).

The second level of capabilities is dynamic capabilities (Teece, 1997; Teece et al., 2018; Zahra et al., 2006). This classification includes: the ability to identify changes and trends, opportunities and threats (sensing), respond to them through action (seizing), and to change organizational culture, business models, etc. (transforming) (see Figure 1).

Following the provided hierarchy, our conceptual model is built on the high-level meta-capabilities, i.e. strategic foresight, strategic agility, and organizational ambidexterity.

Built-in rigidities within management often limit the development of meta-capabilities that subsequently impact a firm's ability to generate excellent performance and sustain competitive advantages (Jiminez-Zarco et al., 2019). Hence managers are the pillars behind the building and embedding them into the organizational culture. They need the ability to sense and seize the opportunity (or threat), orchestrate resources, and adapt the organization and its business model. The visionary role requires propagating the organization's vision and values, aligning people with strategy, and motivating them (Teece, 2018; Chowdhury et al., 2019).

Dynamic Capabilities

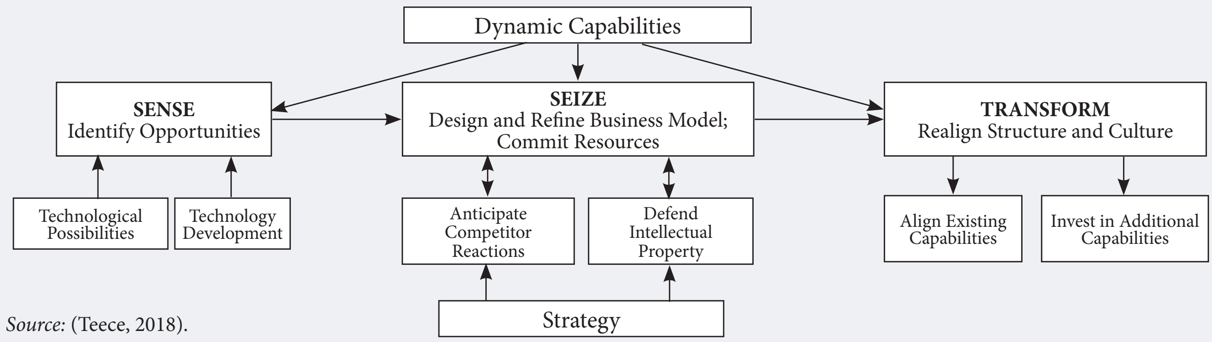
Ability to Sense Opportunities and Threats

In a rapidly changing globally competitive business environment, consumer behavior, emerging technologies and competitors' activities are in a constant state of flux. Opportunities emerge for both incumbents and newcomers (Teece, 2018). Specific emerging trends on the market are pretty obvious, while others are not so apparent. For instance, in the retail sector, consumers' shifting preference to online purchasing was quite evident. The existential need to adopt Industry 4.0 technology to respond to consumer requirements was not apparent to everyone (Wijewardhana et al., 2020). The reality is that most emerging opportunities and threats are not easy to discern unless an organization orients its capabilities. Therefore, sensing new opportunities or threats is scanning the horizon for emergent phenomena, learning rapidly about them, and interpreting the consequences of such changes (Teece, 2018).

The ability of organizations to sense opportunities and threats goes beyond investments in knowledge assets; it is more about having a mechanism by design that constantly assesses how new phenomena are likely to give a quantum boost or pose existential threats to the organization (Randhawa et al., 2020). In specific industries, the sensing capability is noticeably well developed for various reasons that may not be organic. For instance, in the banking industry, periodic stress tests mandated by the BASEL-III accord along with changes in IFRS (International Financial Reporting Standard) compliance regulations force banks with global operations to frequently assess the value of their assets in light of emerging risks by simulating different extreme scenarios (Feldberg, Metrick, 2019).

To sense opportunities (or threats), a firm needs to search and explore markets and technologies constantly, whether said markets be local or far away (Teece, 2018). This requires investment in research activities aimed at probing customer needs and expectations and how new technologies would enable one to address such needs. When the first glimpse of new opportunities or threats appears, businesses with the ability to sense opportunities can interpret such information in terms of "market segments to target" and "technologies to deploy"

Figure 1. **Links between Dynamic Capabilities and Strategy**



Source: (Teece, 2018).

(Zhang et al., 2020). This sensing ability is also likely to include collaboration with key customers and suppliers to assess the nature and potential of these opportunities and threats.

Ability to Seize Opportunities and Evade Threats

When a firm has identified an opportunity (or threat), it has to address it through strategic moves that reconfigure its products, services, processes, or even business models (Zhang et al., 2020). Typically, in the early stages, organizations have to choose between multiple strategies that may be at odds with each other. If the previously physical location of the organization was a vital resource (for example, in the world of retailing), then in the Industry 4.0 context, other capabilities have become more crucial such as agility in deploying technologies such as virtual and augmented reality, 3-D printing, and data analytics (Wagner et al., 2020; Ashdown, 2020; Olaf, Hanser, 2018). Seizing upon novel opportunities involves maintaining and continuously improving assets and competencies (Chowdhury et al., 2019). Firms can move on and invest substantially in the research and development of relevant technologies and designs. A crucial factor is to get the timing right, to start transformations (Wagner et al., 2020). Many organizations sense opportunities and threats and yet decide to remain unfettered on their existing strategies and business models, due to organizational inertia (Wagner et al., 2020). For example, retailers such as J.C. Penney have been in business well over 100 years and decided to stay the course and keep large physical stores that were hemorrhaging cash from the company even though consumer behavior was shifting towards online retail.[2] It is obvious that J.C. Penney's management was aware of the changes in the consumer behavior, however strategic rigidity prevents the breaking out of path dependence. Such rigidity has led such companies near bankruptcy, which has further been accelerated by the COVID-19 pandemic. Therefore, organizations must be geared up to quick decision-making to seize upon opportunities and threats they have sensed, which must be embedded into their organizational decision-making processes. High tech companies such as Apple, Netflix, Google, and others, in contrast with traditional ones, have succeeded in finding novel business models in a timely manner, and thus have become a part of the emerging innovation "mainstream". As a result, just over the last two decades they achieved a market value that is greater than some of the largest traditional companies such as Exxon, Gazprom, GE, Citigroup (Verhoef et al., 2021).

Ability to Transform: Reconfigure Organizational Capabilities

Maintaining evolutionary fitness depends upon an organization's ability to recombine, reconfigure and transform organizational structures and assets together with changes in the markets and technologies (Yu et al., 2018). As more and more assets come under the control of organizations, they need to protect the firm from mismanagement and misconduct by preventing free-riding and manipulating information by dishonest employees. Organizations face such dilemmas as the number of people in their organization becomes more significant with time, and their operations spread out over wider geographical zones (Zacca, Dayan, 2018). Such companies develop rules and hierarchies that eventually begin to constrain their ability to rapidly react to new knowledge and information (Zhang et al., 2020). Changing established routines is costly and causes anxiety within the organization unless the organizational culture is designed to accept high levels of internal changes (Teece, 2018).

Reconfiguration and transformation may involve a re-design of the business model and re-alignment of assets, and revamping of routines. Such re-deployment may be through sharing capabilities between the supply chain partners or the geographical transfer of abilities from one market to another. Both are possible but not accessible unless the organization is designed to transform in response to the environment. To sustain such dynamic capabilities, top management needs a multi-level holistic perception of the wider environment. Strategic decision-making should be aligned within multiple levels of organizational hierarchy and must be focused on market realities (Teece, 2018).

High-Level Organizational Capabilities

Strategic Foresight

Strategic foresight as a tool for deciphering emerging trends, opportunities, risks, and causalities allows the organization to more informed decisions about matters that will impact their strategic decisions and long-term goals. Strategic foresight suggests that organizations recognize that multiple futures are possible. The extant literature also indicates that strategic foresight is comprehended in two different ways. A cluster of researchers view it as a process for re-designing strategies, while others perceive the concept as a basis for strengthening dynamic capabilities (Rohrbeck, Kum, 2018). In the seminal study by Rohrbeck et al. (2015), the authors assert that research on dynamic capabilities should be integrated with strategic foresight, because the concept of organizational foresight and the ability to sense in DCV are conceptually similar.

Strategic Agility

Strategic agility is considered an organization's capacity to undertake strategic long-term commitments and yet remain flexible and nimble, and is the means by which organizations reinvent and transform themselves through adaptability and ensure their survival through uncertainty (Doz, 2020). Strategic agility comprises of three dimensions: *strategic sensitivity*, *leadership unity,* and *resource fluidity* (Doz, Kosonen, 2010). Strategic sensitivity is the sharpness of perception of, and the intensity of awareness and attention to strategic developments. Resource fluidity is the internal capability to reconfigure capabilities and redeploy resources rapidly. Leadership unity is the ability of the top team to make bold, fast decisions. The concept of strategic agility in business organizations can be traced back to the discussions on what types of national strategies were needed to attain leadership in an unpredictable, rapidly changing world (Abshire, 1996). Then this approach migrated to the business environment, where the terms "ag-

[1] https://www.forbes.com/sites/gregpetro/2020/02/17/walmart-challenges-amazon-on-sustainability/#2fdccf65bb8a, accessed 28.03.2022.

ile manufacturing" was introduced to describe the focus on a tailored response to customer needs, arguing that the need for agility ought to take precedence over mass production as the future of 21st century manufacturing (Diego, Almodovar, 2022). Over time the research on organizational agility spread to other areas such as supply chain management, services, and organizational capabilities (Haarhaus, Liening, 2020).

Organizational Ambidexterity

Organizational ambidexterity is defined as an organization's ability to explore and exploit at the same time. 'Exploit' means focusing on current operational activities while 'explore' means focusing on strategic development. (Duncan, 1976; March, 1991) referred to it as an organization's ability to pursue two apparently contradictory goals that are *exploration* and *exploitation*. Exploration refers to risk taking, searching for new frontiers, and innovation, while, exploitation focuses on refinement, focus on efficiency, and execution of current strategies (Brix, 2020). More recent studies have refined the concept further by defining organizational ambidexterity as the ability of an organization to simultaneously pursue incremental and radical innovations, where incremental innovations meet existing customer needs, while radical innovations meet emerging customer needs (Brix, 2020). Hence, ambidextrous organizations are able to expand current activities and simultaneously explore future emerging horizons (Venugopal et al., 2020).

Conceptual Framework and Propositions

It is challenging to maintain sustainable organizational performance in a dynamic environment. Therefore, firms must constantly reconfigure and re-deploy their resources to match rapidly changing circumstances (Teece, 2018). Business organizations require meta capabilities that enable them to create, maintain, and modify strategies and business models to sustain their relevance on the market (Vanpoucke et al., 2014). The digital transformation of organizations in the Industry 4.0 environment would therefore be a rational move if migration to such an ecosystem strengthens their strategic agility and organizational ambidexterity through the enhancement of a firm's ability to sense, seize, and transform their business models as reflected through the manifestation of greater levels of strategic foresight. The logic behind such an assertion may be deduced from observing the strategies implemented by some of the modern-day corporate behemoths such as Amazon, Apple, Google, Tesla, and Alibaba, which have demonstrated high levels of strategic foresight.[3] Their strategic moves are indicative of their strategic agility and organizational ambidexterity. It is obvious that some of these companies realize that future reliance upon targeted social media advertisements on their platforms as their primary source of revenue is unlikely to be sustainable for a long period. Therefore, the organizations not only continue to harvest profits from the ongoing business of targeted advertisements through AI-based algorithms but has also launched itself toward a new futuristic business horizon. The ability of these organizations to sense and seize opportunities and deal with threats through unprecedented levels of strategic foresight has translated into high levels of strategic agility in terms of response to the market, while these companies continue to focus on their existing businesses as well as their development of future opportunities, which is indicative of their organizational ambidexterity.

Table 1. **Priorities for Exploration and Exploitation within Organizational Ambidexterity**

Exploitation focus	Exploratory focus
• Competing on mature markets • Reliance upon mature technologies • Control • Efficiency • Incremental improvement	• Competing for emerging markets • Introduction of new technologies • Experimentation • Autonomy • Risk taking • Innovation

Source: authors, based on (O'Reilly, Tushman, 2004; Brix, 2020).

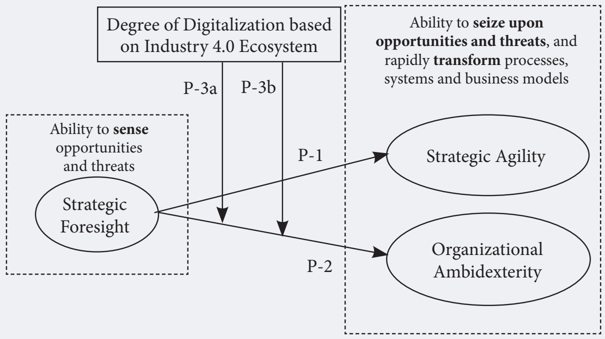
The extant literature on organizational capabilities research indicates that researchers have shown extensive interest in understanding the association between capabilities and firm-level outcomes such as business performance, productivity, internationalization, R&D, and innovation (Khan et al., 2019). However, most of these studies have focused on a particular aspect of capabilities, such as marketing capabilities as part of a wider management capability or IT capability as part of technological capability (Kurtmollaiev, 2020). Furthermore, relatively few studies have examined the combined impact of both management and technical capabilities on CA (Fainshmidt et al., 2019; Kaur, Mehta, 2017). Kurtmollaiev (2020) and Diego and Almodovar (2022) have stressed the need to undertake further research on how the DC of organizations influences high-level capabilities such as strategic agility and organizational ambidexterity. At the same time, other studies suggest that such organizational capabilities are significantly influenced by strategic foresight (Haarhaus, Liening, 2020). However, there appears to be a dearth of sufficient understanding on how the digital transformation of organizations in the Industry 4.0 ecosystem is likely to interact with strategic foresight to drive organizational goals such as agility and ambidexterity.

Although the two constructs *strategic agility* and *organizational ambidexterity* appear to be conceptually overlapping, they are quite distinct, and both represent two different aspects of high-level organizational capabilities (Clauss et al., 2021). Regarding strategic foresight as a potential driver of both the above capabilities, Clauss et al. (2021) conducted a study on 150 German mid-sized businesses in the engineering industry and found that both organizational ambidexterity in conjunction with strategic agility mediated the relationship between strategic foresight and competitive advantage. This finding suggests that strategic foresight has a positive association with both the constructs: strategic agility and organizational ambidexterity.

[2] https://www.forbes.com/sites/michaellisicky/2020/05/17/from-its-beginnings-to-bankruptcy--a-company-timeline-of--jcpenney/?sh=7a3d146d31de, accessed 28.03.2022.

[3] https://www.forbes.com/sites/warrenshoulberg/2020/06/15/its-alibaba-not-walmart-that-amazon-should-be-really-worried-about/#71e2cb627ddc, accessed 28.03.2022.

Figure 2. **Conceptual Framework of Links between Degree of Digitalization and High-Level Meta Capabilities»**



Source: autors.

Furthermore, the literature indicates that the digitalization of organizations positively influences organizational agility (Hadjielias et al., 2022). Meanwhile, Miceli et al. (2021) show that digitalization impacts sustainability, strategic agility, and organizational resilience. Similarly, Park et al. (2020) found that degree of digitalization has a positive association with organizational ambidexterity. In another study by Belhadi et al. (2021), organizational ambidexterity has been found to mediate the relationship between the digital business transformation and Industry 4.0 capabilities and sustainable supply chain performance.

Based on the preceding discourse, it is posited that strategic foresight positively influences both strategic agility and organizational ambidexterity. Furthermore, when such organizations migrate to the Industry 4.0 ecosystem, the degree of digitalization will moderate the relationships between strategic foresight and both strategic agility and organizational dexterity. Therefore, the following propositions are made as depicted in the conceptual framework in Figure 2.

P-1: Strategic foresight has positive association with strategic agility

P-2: Strategic foresight has a positive association with organizational ambidexterity

P-3a: The degree of digitalization will moderate the relationship between strategic foresight and strategic agility.

P-3b: The degree of digitalization will moderate the relationship between strategic foresight and organizational ambidexterity.

Discussions and Future Research Directions

The discourse presented in the preceding sections leads to the proposition of a conceptual framework that asserts that different aspects of meta-capabilities of organizations interact with one another to enhance an organization's ability to deal with uncertainties in the business environment that these organizations are exposed to. Leveraging the three micro-foundations of the theory of dynamic capabilities (i.e., to sense, seize, and transform), strategic foresight is a reflection of an organization's ability to sense opportunities and challenges emerging on the horizon. Furthermore, both strategic agility and organizational ambidexterity are high-level capabilities that reflect an organization's ability to seize upon these opportunities and evade threats as well as rapidly transform their processes, systems, and business models when required. The primary contribution of this study is to argue that the degree to which such organizations adopt digitalization in their processes and systems based on the Industry 4.0 ecosystem, will moderate (in this case strengthen) the relationships between strategic foresight and strategic agility, and also the relationship between strategic foresight and organizational ambidexterity.

The propositions presented in the current study require empirical investigation. A rigorous data-driven examination of the model would likely provide evidence on whether migration to Industry 4.0 technologies drives significant increases in the levels of abilities to sense changes in the competitive environment and then have the rapid decision-making capacity to seize upon emerging opportunities on the business horizon. Subsequently, such decisions have to be backed by the organization's built-in capabilities to reconfigure systems, routines, and possibly business models to bring about the transformation. In addition to testing the framework empirically, future researchers may consider that other variables not considered in this study may influence the relationships. For example, since this study looks at capabilities that enable organizations to cope with uncertainties, other pertinent variables that may play a significant role in the relationships are environmental uncertainty, flexibility, and decision rationality. Furthermore, other strategic goals such organizational resilience, productivity, and competitive advantages may also be considered as outcome variables that provide deeper insights on how digitalization effects capabilities and organizational performance.

Another important construct that may be of significant importance is the potential relationships between the adoption of Industry 4.0 technologies and the abilities to sense, seize, and transform may also be contingent on whether knowledge management within the organization is optimized. Based on prior empirical literature, it appears that knowledge management comprises of four dimensions: acquisition, conversion, application, and protection of knowledge. Each of these knowledge management components is likely to influence the strength of the relationships between strategic foresight, strategic agility, and organizational ambidexterity. Hence, the framework may be expanded further to consider the role of knowledge management. Another important variable that may also be taken into consideration by future researchers is ensuring system security needed for the data protection in the hyper-connected Industry 4.0 environment.

Conclusion

The framework presented in this study is by no means the end of the road. It is a proposition for future researchers to move the initiative forward toward a conceptual model that may be tested and validated through empirical studies. The idea being presented in the current study is to start a conversation that would draw researchers' interest and push them to find a robust model to determine how the capabilities of organizations are impacted when they migrate to an environment driven by the cutting-edge technologies that drive Industry

4.0. The potential impact of the adoption of Industry 4.0 on business organizations' long-term goals is still not clear, and more frameworks need to be developed that enable the measurement of organizational performance when they migrate to such advanced technological ecosystems. In addition to the basic framework outlined in this study, further development toward a sound conceptual model may require the consideration of other exogenous and endogenous constructs not covered here.

The idea behind developing a robust model for measuring organizational benefits resulting from migration to an Industry 4.0 environment remains a challenge. Part of the challenge emanates from the fact that articulating a proper definition of Industry 4.0 has not been easy. People tend to grasp the systems and technologies that drive the fourth industrial age, but defining it clearly and concisely remains a challenge. Despite the popularity of the term Industry 4.0 in academic and management circles, there are more than 100 definitions of this term in engineering and management literature (Culot et al., 2020). According to the consulting firm McKinsey Group, Industry 4.0 is a combination of many managerial and technological concepts and is more or less a confluence of trends and proposals for how products and services should be made and delivered, merging advanced technologies into the production and delivery environments.

Empirical studies related to the impact of the digital transformation upon organizations seems to be mostly limited to parts of the world where research and development related to advanced industrial and manufacturing technologies are more pervasive. While it appears that many emerging economies are also prioritizing the adoption of digitalization, most are lagging behind due to a lack of sufficiently trained personnel.

A contribution of this study may be considered as the step it made toward theory development in terms of relating digitalization to organizational capabilities in an uncertain and rapidly changing world. With advanced technologies becoming ubiquitous in human society, both academia and industry need to get a firm grasp on the benefits and potential challenges that organizations will encounter as the digital transformation becomes more pervasive. Future empirical studies based on such models will enable policymakers to have a better understanding of how to regulate and promote migration to Industry 4.0.

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The Climate Stigmatization of the Global Oil and Gas Industry: Response Strategies

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Abstract

One of the most recent trends in the global economy is the stigmatization of the global oil and gas industry, i.e., the sharply negative public perception of the industry as a whole, and of its key players in particular. These processes, directly related to the aggravation of the climate-related issues, have already become a source of substantial problems for major industry players. In recent years, public opinion regarding major international oil and gas corporations has changed markedly, at least in most Western countries. Global industry leaders (the so-called supermajors) are increasingly perceived as an existential threat to humanity, laying on them the main responsibility for global warming. Faced with the challenges of the industry-level public ostracism (industry stigma), these companies have been the first to develop a set of responses. This paper attempts to take a fresh look at the supermajors' climate strategies for responding to the industry stigma. Looking through the prism of the stigma management concept helps one identify the reasons behind the changes in global oil and gas corporations' relevant strategies in the course of their evolution, and understand the logic behind the different approaches to the green transformation employed by European and US supermajors.

Keywords: stigmatization of the oil and gas industry; stigma management strategies; oil and gas supermajors; corporate climate strategies.

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Introduction

Over the past few years, the growing threat of the stigmatization of the global oil and gas industry has evolved into a new, distinct phenomenon. Even a decade and a half ago the industry was seen as a respectable and attractive investment area or place of work in almost all countries. But with the global warming issue rising to the fore and the rapid growth of the climate activist movement against fossil fuels, the situation has drastically deteriorated. In a very short time the public perception of the largest global oil and gas companies has changed dramatically, at least in North America and Europe. Since the responsibility for global warming was put primarily onto these giants, the public started to perceive them not as respectable members of the corporate community, but as outcasts condemned by all, since their core business has been considered a source of an existential threat to humanity.

Due to the above trends, the oil and gas industry and the fossil fuel sector as a whole in the near future run a high risk of joining the dubious club of "controversial" industries which traditionally include alcohol, tobacco, gambling, and arms production. As a Canadian financial analyst described the current situation, "regardless of one's own personal views on traditional oil and gas companies and their impact on our environment and society, there is no doubt that the grand consensus verdict is already in - guilty. Oil and gas companies of all stripes, from the most junior exploration venture right up to the world's most recognizable names like Exxon Mobil and Royal Dutch Shell, are under considerable pressure from all fronts" (Cherepuschak, 2021).

Today, Western international oil and gas companies have become the main targets of climate-related stigmatization by the public. The largest of them, the so-called supermajors,[1] were the first to face the serious negative consequences of such a severe change in public opinion, so they started thinking about the steps with which to respond to this trend. Even though some researchers have touched upon this topic in their works on oil and gas companies' adaptation to the energy transition and on the impact of the fossil fuel divestment movement (Ansar et al., 2013; Ferns et al., 2019), the specific strategies of these companies to address industry stigmatization remain understudied.

The negative change in public opinion on the oil and gas business was driven by a combination of science and technology, economic, and socio-political factors. The academic community has made a huge contribution to promoting climate-related issues to the rank of a global challenge (Maslin, 2021; Klingelhöfer et al., 2020). Many years of national and international academic debates have not only contributed to making the global warming topic popular, but also led to its perception as an impending global catastrophe, which in its turn resulted in the transformation of research findings into the public policy priorities. In many countries, powerful political parties and social movements have emerged around the green agenda, while at the international level, the climate change issues have become a subject of regular multilateral negotiations in its own right, including at the UN. Their most important outcome was the signing of the Paris Climate Agreement in 2015, which set the key targets for reducing greenhouse gas emissions and transforming national energy systems.[2]

In parallel with these processes, renewable energy technologies (primarily solar- and wind-based) were actively developed and spread, expected to become a real alternative to fossil fuels, and to ensure the transition to a low-carbon energy future. In 2020, renewable energy sources met over 12.6% of global final energy demand, compared to 8.7% in 2009. Particularly substantial shifts occurred in the electricity generation segment, where in just five years from 2015 the share of renewables increased by 13.5 percentage points, reaching 28% (REN21, 2022).

The most reputable forecasts of global energy sector development have long predicted relentless changes in the global energy balance in favor of renewables. Thus, according to the International Energy Agency (IEA) estimates, in 2020-2026 the world's renewable power generation capacity is expected to grow by more than 60% and exceed 4,800 GW, which is equivalent to the current global power capacity of fossil fuels and nuclear combined. Moreover, the accelerated growth of renewables over the same period is to account for almost 95% of the increase in global power capacity through 2026 (IEA, 2021). Another recent world energy outlook developed by BP (2022) suggests that the share of renewables in global primary energy consumption will grow from around 10% in 2019 to between 35% and 65% by 2050, depending on the scenario, leading to the respective reduction of fossil fuels.

At the same time, since the middle of 2021, the situation in the global energy sector has significantly

[1] The experts traditionally include only five companies in the group of the global supermajors: the US-based ExxonMobil and Chevron, the British-Dutch Shell (until January 2022 Royal Dutch Shell), the UK-based BP, and the French TotalEnergies (until June 2021 Total).

[2] Central to the Paris Agreement is the target to keep the rise in the global average temperature well below 2 degrees Celsius above pre-industrial levels, and a commitment to limit the temperature rise to 1.5 degrees Celsius. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, accessed on 22.11.2022.

changed. The acute energy crisis which erupted following the sharp increase in energy demand during the post-COVID recovery of the global economy, and further aggravated by the imposition of Western sanctions on the Russian oil and gas industry, forced the governments in several leading EU countries, as well as in the UK and the US, to ease the pressure on their own fossil fuel sector. To protect the public and home economies from a physical shortage of energy resources, many conventional energy facilities, including the least environmentally friendly coal-fired power plants, are to be brought back into operation in the next few months.[3] The inclusion of natural gas and nuclear energy in the EU's "green taxonomy" in early July 2022 by the European Parliament was particularly indicative, essentially allowing European companies to classify investments in gas and nuclear power plants as green ones. This move provoked strong condemnation by many political forces (Igini, 2022).

The initiators of this reversal in Western countries' energy policies present it as a purely temporary solution aimed at overcoming the crisis in the global energy sector. The vast majority of Western politicians and industry experts are confident that the strategic course toward an accelerated transition to renewables is not only inevitable, but should also serve as the basis for a political response to current energy crisis (REN21, 2022). Therefore, the pressure on the major oil and gas players from the regulatory authorities and public opinion will only increase.

Given the abovementioned gap in academic literature, this paper aims to identify the key challenges faced by the oil and gas supermajors due to the growing industry stigma and the changes in their corporate strategies designed to address these issues. Apart from being of academic interest on their own, the above range of issues can also turn out to be useful for shaping a viable international climate policy. Structurally, the paper is organized as follows. After a brief analysis of the evolving industry stigmatization concepts, the specific features of stigma-related processes taking place in the oil and gas industry are examined, along with the challenges noted above. Next, the evolution of oil and gas giants' climate strategies in the context of dealing with industry stigmatization is analyzed. The final section presents the main conclusions.

The Development of the Industry Stigmatization Concept

The industry stigmatization concept emerged relatively recently. Its origins can be traced in the socio-psychological studies of the 1960s which produced a whole range of constructs and approaches, which were developed further under the organizational theory. Sociologists were not only the first to suggest a detailed definition of the stigma phenomenon in the context of specific relations between various groups of individuals, but also identified its most important characteristics. In social terms, the notion of a "stigma" was initially applied to describe the status of an individual who, for one reason or another, was rejected by society and found him- or herself in a position of an outcast (or a pariah). Under this approach, stigma is seen not as an inherent characteristic, but as an externally assigned attribute, which undermines the individuals' social status and generates a negative attitude toward them on the part of others (Goffman, 1963). Sociologists also made a number of theoretically valuable conclusions that stigma presupposes and maintains a certain social hierarchy, and acts as an important control mechanism (Neuberg et al., 2000; Paetzold et al., 2008).

Transferring the concept of stigmatization into the conceptual apparatus of the organizational theory allowed for applying it to various organizational entities, in particular to enterprises (firms). In this context, stigma is seen as a social construct which arises from a negative collective perception of an organization by various influential stakeholder groups. In (Devers et al., 2009), organizational stigma is defined as "a collective stakeholder group-specific perception that an organization possesses a fundamental, deep-seated flaw that de-individuates and discredits the organization". Unlike individual stigma, which can arise from external differences of the stigmatized targets (e. g. ethnic, religious, and other social characteristics), organizational stigma tends to be behavioral in nature, i.e., it is closely linked to certain actions (or inaction) of the organization's representatives. This is why organizations almost always bear full responsibility for the acquired stigma.

In this context, the idea about the need to distinguish between event-based and core organizational stigma suggested by a number of researchers becomes par-

[3] At the end of June 2022 the German government issued a temporary (until 2024) permission to resume operations of 27 coal-fired power plants, while the governments of France, Italy, Austria ,and the Netherlands announced the need to restart already closed thermal power plants "to avoid blackouts this winter" (Cessac, 2022).

ticularly important (Hudson, 2008; Hampel, Tracey, 2017). Event-based stigma typically arises in response to specific incidents that have serious negative consequences for a wide range of participants. These include, e.g., bankruptcies of large enterprises, environmental disasters caused by irresponsible business practices, corporate scandals related to business misconduct, and so on. The emergence of core stigma is associated with a specific persistent characteristic of the organization directly related to its core activities. Regarding business organizations (firms), such characteristics in most cases are associated with the key parameters of the markets in which they operate (above all with the specific features of their products or customer types). Accordingly, in the latter case, the organizational stigma of an affected firm is closely intertwined with the stigmatization of a particular market or the industry as a whole (Shantz et al., 2019).

A significant level of stigmatization of a particular industry, which essentially means depriving industry players' of their social license to operate, leads to tangible negative consequences for the affected firms, both direct and indirect. Direct effects typically involve the disruption of many important business relationships (with investors, suppliers, and lenders who usually prefer not to deal with stigmatized businesses) and a massive exodus of skilled personnel whose future career prospects may be significantly damaged if they carry on working for such firms (Groysberg et al., 2016). Direct consequences may also include corporate expenditures on paying fines, out-of-court settlements, or legal fees in case of lawsuits initiated by the victims (Grougiou et al., 2016). Indirect effects can be no less painful. As noted by (Vergne, 2012), "a high level of disapproval attracts public scrutiny, raises doubts, and creates suspicion among stakeholders <…>, which increases the risk of isolation and scapegoating for the stigmatised group members that are publicly challenged". In some cases this can lead to artificially low share prices of stigmatized firms (Killins et al., 2020) or to a massive boycott of their products (McDonnell, King, 2013).

To mitigate these negative effects, the firms operating in a stigmatized industry implement various stigma management strategies. Industry stigma researchers initially focused on a defensive type of these strategies based on impression management techniques (Hudson, 2008; Carberry, King, 2012). Such strategies aim to minimize the organization's negative perception solely by PR means, without affecting the actual activities that have caused the public discontent and condemnation.

The biggest contribution to studying such strategies was made by the authors of the corporate image restoration concept, whose foundations were set in (Benoit, 1997). The proponents of this school of thought identified five main strategic options to respond to events causing serious damage to the corporate image: denial, evading responsibility, reducing offensiveness, taking corrective action, and mortification. As the actual experience of applying this concept to restore the reputation of various large companies in different industries has shown, a hybrid approach is usually taken. Firms combine various strategies carefully choosing the options in accordance with a particular set of threats to their image, their own risk assessments, their abilities to influence the situation, and so on (Metzler, 2001; Blaney et al., 2002; Grimmer, 2017).

Another transformational type of stigma management strategy involves real changes in the defamed firm's business. In particular, such strategies include diversification into industries or segments more safe in terms of public opinion, which essentially means expanding the company's business portfolio. An example is Boeing, one of the world's largest aircraft producers, managed to avoid stigmatization as a maker of "instruments of death and destruction" (a wide range of missile and space systems, and other military equipment) by also manufacturing civilian aircraft.

A less studied transformational type of stigma management strategy implies the development of new products, the adoption of innovative technologies and business models. In recent years such strategies have become increasingly popular in the context of the digital transformation of companies in almost all sectors of the economy. A striking example is provided by the fairly successful efforts of Philip Morris and other major tobacco manufacturers to improve their image through introducing radically new products on world markets: electronic cigarettes and digital tobacco heating devices (Gillette et al., 2017).

Finally, the most radical transformational strategy is divesting from the stigmatized industry, either partial or complete (defection). Thus, a special study of the US nuclear industry concluded that "higher stigma intensity also results in a higher likelihood of defection" (Piazza, Perretti, 2015).

The latest research on industry stigmatization revealed a number of new factors significantly affecting cor-

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[4] Each of these strategies can be further broken down into several sub-strategies. Thus, the denial strategy can take the form of denying the very fact of reprehensible behavior or the involvement in it, or shifting the blame (scapegoating) by arguing that there is another, true culprit, etc.

porate stigma management strategies. This is about an increased understanding of the cultural and value diversity of the public as factor in the emergence of a negative attitude toward a particular industry (Smith et al., 2021), and a broader comprehension of the drivers of industry stigma spreading, especially regarding the roles of social movements, NGOs and social networks (Ferns et al., 2021). At the same time the current mechanisms of the industry stigma emergence remain outside the scope of the abovementioned studies: what causes stigmatization of industries which until recently remained perfectly respectable; what are the key driving forces of this process; how the response strategies of the leading players in the stigmatized industries evolve as the stigma grows, etc. An analysis of various aspects of the oil and gas industry stigmatization, and of the specific strategies implemented by the supermajors to address industry stigma, will help to answer these questions.

Stigmatization of the Oil and Gas Industry and Challenges for the Supermajors

Though it is rather difficult to determine the starting point of the stigmatization process in the global oil and gas industry, many researchers associate it with the emergence of a massive Fossil Fuel Divestment Movement (FFDM) in Western Europe and North America in 2011 (Ansar et al., 2013; Gunther, Ferns, 2017). While the key role in creating fertile soil for industry sigma was played by the climate science community and state policymakers (in the countries which took firm steps towards decarbonization), the real driving force behind the deliberate destruction of the industry's reputation and the discrediting of its major players, were climate activists, and above all the FFDM. The successful campaign to divest from South Africa during apartheid in the 1980s gave the initial impulse to this movement. In June 2012 the prominent US ecologist Bill McKibben published an article which became a kind of FFDM manifesto (McKibben, 2012). The main thrust of the paper and its emotionally expressive style (as well as that of the subsequent publications) leave no doubt that the stigmatization of the fossil fuel sector, including the oil and gas industry, was the movement's key priority from the very start. Firstly, the fossil fuel sector was directly named as the main culprit of climate change, threatening the existence of life on the planet, and therefore declared a public enemy that must be destroyed. Secondly, moral condemnation of fossil fuel companies for profiteering from climate destruction was announced as the central area of the FFDM efforts (McKibben, 2013).

The important specific features of the FFDM approach include reliance on think tank networks focused on the green agenda, especially on the Carbon Tracker Initiative (CTI), and the public naming of stigmatization targets among the leading oil and gas (and coal) industry players. One of the first steps taken by the movement founders was publishing a list of divestment targets among the world's top 200 fossil fuel companies, both private and state-controlled.[5] This personification of the biggest culprits of climate change became a powerful catalyst for the deterioration of their public image.

The participants in FFDM made no secret of the fact that their ultimate goal was to instill into the mass consciousness a toxic image of the fossil fuel sector in general, and the oil and gas industry in particular, to discredit the industry leaders, and to deprive them of government support. According to a member of the movement, "the aim has been to remove the social license of the fossil fuel industry, creating a stigma that would open the door for broader restrictive legislation, and create broader shifts in political, social, moral, and even financial norms" (Lenferna, 2018).

The FFDM's efforts to create and spread industry stigma started to bear fruit very quickly due to a number of factors. Firstly, a growing proportion of the population, mainly in Western countries, became painfully aware how real the global warming threat was. So the prompt identification of the culprits for public condemnation has become a sort of social imperative. Social psychologists have long since demonstrated that "what represents a physical danger for others, is systematically stigmatized" (Vergne, 2012).

Secondly, the oil and gas and coal industries themselves were partly responsible for becoming the "natural suspects" in climate-related problems, due to their dubious environmental track record and reputation tarnished by many human-caused disasters. Throughout the global oil and gas industry's history, environmental incidents occurred with depressing regularity all over the world, and their scale has only grown along with the increasing complexity of oil and gas technologies.

Thirdly, the smart tactics employed by the FFDM leaders to deliberately stigmatize the fossil fuel sector played an important role, effectively combining the tried and tested techniques of past social movements, such as those against the tobacco industry or the apartheid in South Africa. A study of these practices by the

[5] The list was borrowed from the report by Carbon Tracker Initiative (CTI, 2011), which actively feeds the FDDM with new climate policy-related ideas and materials. It comprised the world's top 100 listed coal, and top 100 listed oil and gas companies ranked according their fossil fuel reserves.

British-German group of researchers demonstrated that FFDM activists successfully borrowed various methods from the past mass campaigns, including the construction of "a stark dualistic moral contrast", which "painted the target of stigmatisation as completely evil, while those doing the stigmatising as entirely moral in their quest for justice" (Ferns et al., 2021).

Fourthly and finally, the active use of social networks in the global media space by the FFDM contributed a lot to the rapid spread of industry stigma. Unlike traditional media which often prefer not to disseminate negative information about solid businesses, to avoid the risks of losing advertising revenues and lucrative contracts (and facing lawsuits), social networks as virtual platforms for sharing information between individuals have no economic links with these organizations, and therefore enjoy much greater freedom to express various views. Furthermore, social networks are in no way constrained by journalistic ethics. Consequently, they do not need to be neutral and objective, and are not required to verify information they disseminate (Etter et al., 2019). As a result, the information circulating on social networks often turns out to be much more subjective, strengthening the emotional assessments of organizations and creating favorable conditions for their stigmatization.

What were the main challenges faced by the world's largest oil and gas companies due to the rapidly growing stigmatization of their industry? One of the most serious blows the FFDM dealt to the industry leaders was focused on their financial potential, or rather, on their ability to attract external funding. The FFDM ideologists tried their best to restrict the access of the largest industry players to external sources of finance as they considered this approach to be an effective means of undermining the supermajors' market positions and economic influence. At the same time, unlike other mass divestment campaigns, the climate activists used not only public shaming tools to discredit the targets of their attack (appealing to the moral principles of the audience), but also purely economic arguments.

In this case, the demands to divest from the fossil fuel sector had to be supported with economic arguments because of the specific features of the mechanism chosen to put destructive pressure on the largest industry players: institutional investors, the traditional financial backbone of the sector. The Carbon Tracker Initiative (CTI) experts were instrumental in suggesting the appropriate arguments: they perfectly understood the workings of the financial sector, and the peculiarities of its interaction with the oil and gas industry players. So they came up with the "unburnable carbon" and "carbon bubble" topics (CTI, 2011) closely intertwined with the stranded assets concept.[6]

According to CTI estimates, 60%-80% of publicly listed fossil fuel reserves should be recognized as "unburnable" to prevent catastrophic climate change (CTI, 2013). Further reasoning led to the conclusion about the significantly increased risks of investing in fossil fuel companies. Since their share prices are largely determined by the size of their hydrocarbon reserves, and the projected prices for them, the threat of these assets' depreciation poses a serious risk of the collapse of oil and gas companies' shares, especially under much more stringent climate policies in their home countries. The inevitable mass exodus of investors from fossil fuel companies' capital would result in the burst of "carbon bubble", which in turn will likely provoke a major financial crisis.

The use of economic arguments has not only significantly strengthened the moralistic rhetoric of the FFDM activists, but also enabled the further expansion of the movement (including those who actually shared its ideas, and casual fellow travellers not ready to resist the aggressive mainstream). As a result, from 2014 to mid-2021 the number of financial institutions publicly committed to at least some form of fossil fuel divestment increased from just 181 to 1,485, while the assets under their management grew from approximately 52 billion to 39.2 trillion USD (IEEFA, 2021).

Despite the increased scope of FFDM activities and the rapid growth in the number of its supporters in financial sector, many analysts remain very sceptical about the movement's direct impact on fossil fuel companies. The share of investors ready to stop investing in this traditionally highly profitable sector appears to be not large enough to seriously undermine its economic foundations. The sale of industry companies' shares only leads to a change of owners, i.e., the redistribution of assets among investors. A recent study showed that despite the rise of the FFDM, the global oil and gas sector's fundraising on average grew at over 8% per year since 2008 (Cojoianu et al., 2021). Another reputable research study (RAN, 2021) revealed that despite the world's largest investment banks declared loyalty to the green agenda, their investments in the fossil fuel sector in 2016-2020 have only increased.

However, it would be wrong to conclude that the growing industry stigma does not pose any threat to the financial stability of the global oil and gas corporations

6 In the context of the climate agenda, stranded assets refer to investments or assets that will become prematurely obsolete and consequently losing their value due to the green transformation of the global energy sector.

at all. First of all, attention should be paid to the long-term dynamics of indices that reflect the companies' positions on stock markets: these are traditionally seen as important indicators of general economic health in a particular industry and its investment attractiveness. In particular, the dynamics of stock indices, such as the S&P500 and MSCI Europe Index[7], show that since 2012, the financial positions of oil and gas companies have been steadily deteriorating compared to other industries (Ameli et al., 2021). And though fundamental macroeconomic factors, and then the consequences of the pandemic have undoubtedly made a decisive contribution to the development of these negative trends (for more details see (IEA, 2020)), the industry stigmatization has clearly played significant role too. Thus, a BCG survey of the 250 largest international institutional investors in the oil and gas industry conducted in 2021 showed that over 57% of them felt pressured to divest from the fossil fuel sector, 65% to decrease the weight of fossil fuels in their portfolios, and 75% to invest in green funds and stocks (BCG, 2022).

An increasingly serious problem for the global oil and gas corporations is related to the growing difficulties with recruiting and retaining skilled personnel due to the industry stigma. Despite fairly high starting salaries compared to other industries, educated young people in North America and Europe tend to see working in this sector as an unappealing prospect, mainly due to the sharp decline of its reputation. A survey of 1,200 young university graduates in the United States conducted by EY (2017) revealed that 44% of the respondents aged 20 to 35 do not consider a career in oil and gas to be an attractive option, while the similar indicator for respondents aged 16 to 19 was as high as 62%. According to KPMG (2022), 56% of the industry employees, motivated by similar reasons, are actively considering jobs with renewable organizations, and 43% have already decided to quit within the next five years.

Another looming threat facing the global supermajors due to the industry stigmatization is posed by the significantly increased risks of regulatory intervention, including possible lawsuits demanding compensation for climate change damages, the adoption of new legislation to limit greenhouse gas emissions, the introduction of new types of reporting on low-carbon development, and so on. In May 2021 the Hague District Court ruled that Shell must reduce its global net carbon emissions by 45% by 2030 compared to 2019 levels (Rechtspraak, 2021). In other words, Shell became the first of the global oil and gas supermajors that was ordered by a court of law to bring its strategy in line with the Paris climate agreement. Whether the courts in countries where other oil and gas giants' headquarters are located will follow suit remains to be seen, but the very precedent has already created enormous risks for these companies' further operations, at least in Europe and the United States.

The Evolution of Corporate Strategies to Address Industry Stigma

As the stigmatization of the oil and gas industry increased, along with the negative consequences for its leaders, the attitude toward the problem on the part of the affected companies also changed. At first, these challenges were perceived by the top management of oil and gas corporations as ordinary, or very remote risks, but over time they were increasingly recognized as top priority threats, and moved to the fore of the corporate agenda. Initially, activities in this area did not extend to developing full-fledged strategic documents setting long-term goals and specifying relevant action plans. Rather, strategic responses have taken place less formally, under the broader objectives of corporate image management and strengthening business reputation, most often included in sustainability programs.

In the 1990s, the sustainable development concept became widely accepted as the dominant strategic paradigm of large international businesses in general, and the global oil and gas industry leaders in particular. This was reflected, among other things, in the adequate perception of regulatory measures limiting their environmental impact. However, for a long time this attitude did not extend to the area of climate change response (Boon, 2019). The negative reaction of the oil and gas giants to any kind of climate regulation was quite predictable, since in the absence of affordable technological solutions, meeting these requirements essentially created a serious threat to the supermajors' traditional business model.

It was no coincidence that the initial response of the oil and gas giants was reduced to the total denial of human-induced climate change. A number of US industry associations were engaged to defend the interests of the biggest fossil fuel companies as opponents of climate regulations. The supermajors, in particular ExxonMobil, set the tone in shaping the strategy and tactics of these organizations.[8] Though in the 1990s the formal tasks of these associations were mainly limited

[7] These indices are widely used by investors to assess the financial results of large companies traded on the stock markets in the US and Europe, respectively.

[8] These include, in particular, the oldest US oil producers association (American Petroleum Institute, API), and the Global Climate Coalition (GCC) established in 1989 specifically to lobby in the interests of the largest oil and gas and coal companies in the field of climate regulation.

to opposing the introduction of any emission regulations (including participation in developing the US position at international climate negotiations), in effect their strategy perfectly fit into the classic framework of defensive behavior addressing the emerging industry stigma with well-tried image restoration techniques.

The collective defensive strategies of the oil and gas giants were based on a combination of two key tools. On the one hand, the main efforts were focused on denying the very existence of human-induced climate change using influential but obviously biased pseudo-scientific ("junk science") reports produced by formally independent research centers which received generous funding from the largest oil and gas companies (Oreskes, Conway, 2010). The basic tactics chosen in this case was "raising questions about, and undercutting the prevailing scientific wisdom on climate change to cast doubts in the mind of the public and policy-makers on the existence of a problem" (Van den Hove et al., 2002).

On the other hand, the so-called methods of reducing offensiveness became no less important in countering the growing industry stigma. By adopting these methods, the supermajors sought to prove to consumers that the attempts to build up pressure on the oil and gas industry by tightening climate regulations were fraught with very serious consequences and that their negative effects could become unbearable for the national economy (especially since the very existence of human-induced climate change was called into question). In particular, public attention was drawn to such destructive consequences as reduced energy access for consumers, increased fuel costs, higher taxes, and even a redistribution of national wealth in favor of other countries – major oil and gas exporters.

By the beginning of the 2000s, the defensive strategy that the supermajors employed to address the industry stigma had undergone some changes. The prevailing global consensus on the anthropogenic nature of climate change has left little room for climate sceptics to continue to deny the catastrophic consequences of this process. One after another, the oil and gas giants began to recognize the importance of global warming and to curtail their direct lobbying campaigns against climate regulations. However, these shifts did not mean that the strategies to address the climate change-related industry stigma were abandoned. Rather, they were modified using communication tools to shift the focus from "explicit doubt" (about the existence of an anthropogenic global warming problem) to "implicit acknowledgement confused by 'risk' rhetoric". This conclusion was based on a detailed analysis of more than 200 ExxonMobil communications since 2017, including external publications, advertisements, corporate reports, and other documentation. The thrust of corporate rhetoric moved on to "shifting responsibility for global warming from the fossil fuel industry and onto consumers" (Supran, Oreskes, 2021).

BP came up with an even smarter communication approach to address the industry stigma. It was this British supermajor that introduced the very concept of a "personal carbon footprint" into global circulation. The company started to actively promote this idea under a large-scale (about 100 million USD) marketing campaign in 2004-2006. To organize this campaign, BP brought in marketing professionals who developed a personal carbon footprint calculator which, in effect, elegantly shifted the responsibility for climate risks from the oil and gas industry to consumers of its products (Schendler, 2021).

Since about 2015, one could notice a major turning point in the strategic positioning of the supermajors regarding the climate agenda. Climate scepticism and attempts to avoid responsibility for growing climate-related threats began giving way to specific roadmaps containing concrete steps aimed at reducing greenhouse gas (GHG) emissions, or even certain initiatives for the greening of corporate business models.[9] Essentially this shift is about the transition to transformational strategies which go beyond purely media-communication tools in interactions with the public, and may include measures related both to the introduction of new low-carbon technologies, and to the structural reorientation of the core company business into other energy segments untainted by the stigma, above all to the rapidly growing renewables.

These changes were most clearly manifested in the contents of strategic plans and decisions related to the climate agenda. From 2017-2018, all supermajors began to publish special strategy papers presenting their own climate-related vision and goals, and then regular implementation progress reports. This in itself represented a significant change compared to the previous period (when climate issues were buried in the broader sustainability agenda), and signaled a dramatic increase in the importance of the climate problem for the global positioning of oil and gas businesses. In the relatively short period of time since the supermajors began to develop their climate strategies, a certain standard approach to the content of such documents

[9] See, e.g.: https://www.investopedia.com/terms/g/green-investing.asp, accessed on 22.11.2022.

Table 1. **Oil and Gas Supermajors' Climate Strategies: Measurable Goals, and Planned Initiatives with a Transformative Potential, 2020-2021.**

Key aspects of climate strategies	BP	Shell	TotalEnergies	ExxonMobil	Chevron
Adopting low-carbon technologies while maintaining traditional business model					
Setting measurable targets for reducing greenhouse gas emissions	✓	✓	✓	✓	✓
Applying carbon capture and storage technologies	✓	✓	✓	✓	✓
Investing in research and development of low carbon technologies	✓	✓	✓	✓	✓
Production of new motor fuel types	✓	✓	✓	✓	✓
Diversifying into new industries, which involves changing business model					
Setting zero emissions goals	✓	✓	✓	—	—
Investing in renewable energy (wind, solar, etc.)	✓	✓	✓	—	—
Investing in electric charging stations	✓	✓	✓	✓	✓

Source: author, based on data from (BP, 2020; Chevron, 2021; ExxonMobil, 2022; Shell, 2021; TotalEnergies, 2021).

has emerged, which allows one to identify their common and specific features (Table 1).

An analysis of these climate strategies revealed, among other things, that their main goals and planned actions perfectly fit into the logic of transformational counter-stigma response. These measures evidently go beyond purely media-communication influence on the target audience, and imply making actual efforts to decarbonize the supermajors' business. At the same time, the planned actions can be broken down into two main groups in terms of their nature and depth: (1) adopting low-carbon technologies, while maintaining the traditional oil and gas business model, and (2) diversifying into new energy segments, especially renewables, leading to the transformation of the traditional business model.

The differences between these two types of transformational strategies largely reflect the different approaches taken by the European and US supermajors to address climate-related issues. While BP, Shell, and TotalEnergies opted for a transition to various renewables and achieving absolute net zero,[10] ExxonMobil and Chevron have set a course toward reducing the carbon intensity of their operations while avoiding the risky restructuring of the current business model. As Daniel Droog, Chevron's Vice President for Energy Transition noted, "Our strategy is not to follow the Europeans. Our strategy is to decarbonize our existing assets in the most cost-effective way, and consistently bring in new technology and new forms of energy. But we're not asking our investors to sacrifice return, or go forward with three decades of uncertainty on dividends" (Krauss, 2020).

As soon as the very first climate strategies of the supermajors were published, they have been harshly criticized by climate activists, analysts of intergovernmental organizations, and experts from various research centers (Oil Change International, 2020; CTI, 2021; Naimoli, Ladislaw, 2019). Initially, the main criticism addressed the emission reduction targets (set in corporate strategies) and the planned investments in renewable energy - most often declared insufficient to ensure energy transition and meeting the goals of Paris climate agreement. Very soon after the focus began to shift toward the discrepancies between the declared objectives and their practical implementation. Many researchers noted that the supermajors' climate strategies constituted more pledges than actual action plans (Van Lierop, 2022). A group of Japanese scholars conducted a thorough analysis of climate strategies, and of their implementation by the four supermajors (BP, Chevron, ExxonMobil, Shell) in 2009-2020, and concluded that despite "increasing tendencies towards strategies related to decarbonisation and clean energy", these strategies were "dominated by pledges rather than concrete actions", while "continuing business models' dependence on fossil fuels, along with insignificant and opaque spending on clean energy" was quite evident (Li et al., 2022).

Without questioning the accuracy of these assessments it should be noted, however, that they all stem from the evaluation of the analyzed strategies from the perspective of their potential contribution to solving the climate problem. However, the supermajors usually follow a completely different logic of behavior. As for any corporate entity, the main and unconditional

[10] This concept implies achieving zero emissions across the company's entire value chain, including scope one (GHG emissions as a result of direct production activities), two (emissions of the company's partners, e.g. suppliers of electricity, equipment, etc.), and the most difficult to achieve scope three (emissions resulting from the consumption of the company's products by its customers). https://www.treehugger.com/forget-net-zero-target-should-be-absolute-zero-5194775, accessed on 17.11.2022.

priority for them is to protect shareholders' financial interests, primarily short-term ones, reflected in regular financial statements.[11] From this angle, the management is concerned about the climate issues only to the extent the solutions can extend the social licence for company operations under the growing public pressure on the oil and gas industry. This is why to understand the true motives of the largest industry players regarding the adoption and implementation of climate strategies, these documents should be evaluated not in terms of their contribution to solving climate-related problems, but from the perspective of addressing the industry stigma. This approach sheds light on many issues related to the content of corporate climate strategies and the specifics of their implementation. Thus, many experts criticize oil supermajors for relatively modest investments in new energy.[12] But as empirical studies have shown, it is the very fact of investing in other industries untainted by stigma, and not the amount of these investments, that makes companies' transformational counter-stigma strategies effective. Even relatively small volumes of such investments usually turn out to be sufficient to dilute the association with stigmatized products (Vergne, 2012).

The analysis of the corporate response strategies addressing industry stigmatization allows one to take a fresh look at the origins of the different approaches to climate-related issues employed by the European and US supermajors. The divergences in the climate strategies of companies that operate across national borders in the same global industry, respond to common external challenges, and traditionally rely on very similar business models, initially appears quite hard to explain. Furthermore, in recent decades, the trend was rather opposite: the positions of global oil and gas giants were getting closer in many key areas. However, it is precisely in the climate sphere that their strategic approaches have begun to diverge sharply, and the main reason for this seems to be the fundamentally different level of industry stigmatization pressure these companies experience in their home countries (where the majority of their shareholders are based). In particular, according to special surveys, the majority of the population in major European countries is much more concerned with climate issues than in the United States.[13] In Europe, unlike in the US, both societal and government support for climate policy has created conditions which encourage the adoption of proactive corporate environmental strategies. Under mounting public pressure, top management of European oil companies have made stronger public commitments to climate action and sustainable development in general (Boon, 2019).

Conclusion

The approach chosen to analyze corporate climate strategies in response to the growing industry stigmatization on the whole has turned out to be quite productive. Firstly, it allowed for identifying the main challenges that the global players in oil and gas industry face in the financial, HR, and regulatory spheres due to deliberate public pressure initiated by climate activists. It was these challenges that gave the initial impetus to the emergence of specially designed climate strategies - essentially the main instrument the supermajors applied to address the industry stigma. Secondly, this approach allows one to trace the evolution of these strategies: from the total denial of the human-induced climate change to shifting the responsibility for global warming onto consumers by means of special communication tools, and then to adopting transformational strategies which involve the introduction of new low-carbon technologies and entering into the renewable energy segments. Thirdly and finally, looking through the lens of stigmatization makes it possible to understand the reasons for significant differences between the climate strategies employed by the European and US supermajors.

Another part of our findings relates to the impact of the stigmatization of the oil and gas industry and its leading players on the ongoing transformation of the global energy sector. In our opinion, the rapid development of oil and gas stigma is largely attributable to the willingness of governments, which have decisively embarked toward decarbonization, to use this stigma as an instrument to accelerate the energy transition. So far the outcomes of this approach have been mixed. The pressure of Western governments on their home-based oil and gas companies is clearly excessive. The tacit and sometimes open support of climate activist movements as the drivers of industry stigmatization has made a significant contribution to the current sit-

[11] One of the main barriers hindering the large-scale penetration of supermajors into the renewable energy sector, most often referred to by the management of oil and gas giants, is its relatively low profit margins. Global industry players' shareholders are accustomed to traditionally high returns (at 15-20% on investments in oil production), while renewables typically return between 5% and 10%. As Mark Lewis, a respected analyst at BNP Paribas points out, "the so-called yield gap is the most important blocking factor in these companies' path into the renewable energy sector" (quoted from: (Edwards-Evans et al., 2020)).

[12] Indeed, according to a number of studies, the share of such investments in supermajors' total capital investments does not exceed 1%-2.5%. (Shojaeddini et al., 2019; Murray, 2020).

[13] According to a 2021 survey, at least 75% of residents in Germany, France, Italy, Spain, and Greece expressed their concern that climate change will, at one stage or another, negatively affect their lives, while in the US the relevant figure was 58% (Pew Research Center, 2021).

uation of an acute shortage of investments in the oil and gas sector, and largely provoked the current energy crisis. It is no coincidence that some prominent figures of the global energy sector are pointing at "demonization" of the oil and gas companies in Western countries as one of the key reasons for the dangerous underfunding of the industry (Slav, 2022).

On the other hand, the recent experience of the inept use of industry stigma in energy policy does not negate its transformational potential. Stigmatization is evidently becoming a powerful instrument for bringing additional public pressure to bear in order to accelerate the technological restructuring of traditional industries by discrediting their mature segments based on conventional technologies, and promoting the development of new ones which require significant investments in their technological foundations (e.g. renewables in the energy sector). This topic seems to be a promising area for further research.

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Collegial Forms of Implementation of Directionality in National Innovation Strategies

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Abstract

The normative turn that occurred as a result of radical reforms in science, technology, and innovation policies in various countries has sparked a broad discussion around the "directionality-neutrality" dilemma in science, technology, and innovation (STI) development strategies. However, despite a number of recent publications and science and innovation policy programs, the relationship between these two principles, including the practice of their application by government agencies, remains understudied. A representative analysis (using qualitative methods) of the two national STI councils and their role in strategy development, focusing on the process of approach selection and its value orientation, will fill this gap. On the basis of the collected information and scientific literature, the connection with different policy options is identified. It is shown that the role of the councils is determined by their powers and resources and the boundaries of relevant practices and directions for further research are outlined.

Keywords: directionality; STI strategy; national policy councils; innovation policy; research policy

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Introduction

Organizations commonly aim to fulfill long-term objectives through defining strategies, sticking to the path they defined, and after a few years, they assess their advances and refresh their goals. These strategies are a customary step in positioning the definitions of medium to large companies and non-governmental organizations. However, experiences with different outcomes have shown that for many reasons, ranging from ideological to practical, it is not evident that countries and their successive governments should create and follow a strategy for their development. However, one of the fields emerging more clearly in the past century to be steered by a strategy is industrial policy[1] (Borrás, Edquist, 2019). This domain has seen a revival in the past decades and is currently considered mainstream, reaching its fourth wave (Andreoni, Chang, 2019). In this context, directionality – understood in this field as the ability to identify strategically oriented areas of opportunity for progress, while positioning, devising, and acting toward their achievement – of the innovation systems seems to emerge as part of a third wave of industrial policy, which highlights the relevance of internal competition and cooperation, institutions for policy implementation, and producers' learning processes (Andreoni, Chang, 2019).

The discussion on directionality has recently become the focus of Science, Technology, and Innovation (STI)[2] Policy. When approaching these three ideal types of policy domains, though, their definitions have not necessarily affected them in the same way. Science policy has demonstrated a mostly neutral approach regarding specific areas or sectors, and technology policy has experienced a highly directional basis, while innovation policy has shared different realities between countries and times (Lundvall, Borrás, 2005). These definitions put a new burden on governments' capacity to call for a broad exercise of governance to enhance their strategic, inspiring, and coordination roles (Boon, Edler, 2018). In particular, for the case of specific strategies, this process is reinforced by addressing rationales that could be defined as systemic and evolutionary, due to the role of policymakers as *organizers* rather than *planners*, with a specific approach to networks and sectors (Laranja et al., 2008).

The relevance of studying the specific STI strategies that countries develop to foster progress lies at the roots of the National Innovation Systems approach. Since knowledge is a *fundamental resource* embedded in the institutions of a given country, and these institutions and systems are inherited and evolve with them, these new strategies provide fresh guidelines for the system and the development of its components (Acs et al., 2017). In the definition of STI strategies – under the umbrella of '*isomorphic pressures*' (Irwin et al., 2021) – National Policy Councils (NPCs) for Science, Technology and Innovation (STI) are becoming one of the common responses that governments have implemented to achieve better levels of societal coordination and governance for STI policy. Strategic definition often has to address prioritizing among different lines of work, either by their nature, objectives, instruments, or outcomes. One of these definitions, regarding a non-neutral approach toward an object or subject, is commonly termed '*directionality*'. Following this notion, the science, technology, and innovation strategies[3] for specific areas, sectors, or regions are becoming a mandatory policy instrument for countries and territories in the context of increased attention to directionality. Some efforts are underway to define Missions[4] (Mazzucato, 2018), or Grand Challenges (Kuhlmann, Rip, 2018), or address the dimensions of Responsible (Research and) Innovation (Stilgoe et al., 2013), and in some cases also identify their potential and develop strategies for smart specialization (Capello, Kroll, 2016), among other discussions and challenging the current trends about the governance of socio-technical systems and the role(s) of the state (Borrás, Edler, 2020).

However, there is some academic consensus that this governance as an understudied subject (Borrás, Edler, 2014; Edler, Fagerberg, 2017). Meanwhile, despite some individual efforts, the role of councils within this governance has not appeared to gain scholarly attention yet. In this context, despite the increasing interest in NPCs, there is little evidence about how these organizations relate to one another within their national innovation systems, and how the councils shape (or are shaped) by the national strategies for STI definition. The definition of strategic priorities is commonly highlighted as one of the more common tasks of an NPC for STI. For instance, 74% of the OECD countries have councils (Borowiecki, Paunov, 2018). However, given the highly prescriptive nature of the innovation studies field (Flanagan, Uyarra, 2016) and STI policy's description of the *modus-operandi*, the implementation stage of these processes typically falls short (Breznitz et al., 2018). This happens even when the definitions surrounding the aforementioned topics challenge the different levels of STI policy and their coordination profoundly (Lindner et al., 2016).

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[1] There is some scholarly discussion about how and whether the concepts of innovation policy, industrial policy, science policy, technology policy, or research policy address different topics (Edler, Fagerberg, 2017). Disentangling this problem lies beyond our scope here, but we recognize that most of them are policy domains on their own and overlap among them is evident.

[2] Treated commonly together, in the last few years this was defined as Research and Innovation Policy in most countries, STI policy has been considered a common and unique policy domain (Edquist, 2018).

[3] These strategies may share some commonalities with the renowned concept of *clusters* developed by Michael Porter (Porter, 1998), recently addressed in this context by Wilson et al. (Wilson et al., 2022), but should not be confused with this since critical features of the latter concept – such as its advantages, the concentration of actors, or the focus on productivity – may or not be active in the areas defined in this case.

[4] For a detailed approach to the concepts of missions, challenges, and responsible research and innovation, please refer to (Flink, Kaldewey, 2018).

In such a context, this article aims to shed light on how National Policy Councils, a specific type of organization for STI, conduct one of their canonical tasks: to provide advice for STI strategies. From an inductive perspective, as is customary in this academic field (Martin, 2012), we face some challenges faced by others in the Innovation Studies field regarding the directionality of innovation (Martin, 2016). The specific objectives of this document are:

- To illustrate the role of two different types of National Policy Councils for STI in the strategy-making process for research and innovation areas derived from a strategic selection process.
- To compare the policy options derived from the governance process within which the NPCs participate, stressing the relevance of the NPCs' organizational design for their role in the strategy-making process.

An exploratory and descriptive comparative case study between two NPCs for STI was conducted to fulfill our research aims. The chosen cases were Chile and Spain due to their councils' participation in the definition of their specific STI strategies for Risk Disaster Resilience and Artificial Intelligence, respectively. The methodological approach included interviews with the members of both councils and a secondary data review.

Definitions and Theory

In this section, we present the theoretical frameworks underpinning this research. These frameworks are divided between the object approach of the National Innovation Systems and NPCs for STI and the intra-disciplinary approach of the study of strategies and their focus in science, technology and innovation.

National Innovation Systems and the National Policy Councils for Science, Technology and Innovation.

The complexity involved in the National Innovation Systems, derived from the number of actors and interconnections (Edquist, 2005), implies a need for coordination. The common objectives for science, technology, and innovation require a long-term coordinated strategy to approach to their potential. Moreover, governments and innovation policies are increasingly concerned about how to address societal challenges and no longer exclusively focused on economic goals (Fagerberg, 2017). Following this, the canonical organization of National Policy Councils for Science, Technology, and Innovation has often been presented as means for more coordination in innovation policy (Foxley et al., 2015; Edler, Fagerberg, 2017), particularly for the objective of setting long-term direction and coordination (Fagerberg, Hutschenreiter, 2020).

STI policy organizations require more in-depth understanding. Previous works have established the foundations of modern research on the types of organizations for STI. At an operational level, the classification of research agencies according to their position within the state, their task distribution, and their organizational forms has been proposed (Lepori, Reale, 2019). Similar work has been performed on the innovation agencies and the scope and nature of the innovation fostered by them (Breznitz et al., 2018). Further, a taxonomical study of Public Research Organizations according to organizational dimensions such as structural characteristics, resource niches, and claims of identity, has been performed (Cruz-Castro et al., 2020). On a strategic level, an empirical map and a classification based on the structural characteristics of NPCs for STI, built on some of the characteristics highlighted in previous classifications, have been proposed (Schwaag-Serger et al., 2015; OECD, 2009; OECD, 2018), while addressing the black-boxed and unproblematic approach commonly developed for NPCs (Cevallos, Merino-Moreno, 2020). On the other hand, qualitative approaches have been discussed for case studies based on the experience of the former Finnish Science and Technology Policy Council (STPC) (Pelkonen, 2006), the Swedish National Innovation Council (NIC) (Edquist, 2018), and partial looks at the councils of Finland and Sweden councils (Fagerberg, Hutschenreiter, 2020). Further a case study focusing on a comparison between the councils of Chile and Spain was written (Cevallos, Merino-Moreno, 2021).

Strategy and Directionality

As mentioned in the introduction, NPCs commonly participate in STI strategy definition for their countries. The objectives of an STI strategy were defined by the OECD a few years ago:

> '*First, they articulate the government's vision regarding the contribution of STI to their country's social and economic development. Second, they set priorities for public investment in STI and identify the focus of government reforms (e.g., funding of university research, evaluation systems). They also mobilize STI actors around specific goals (…) Third, the elaboration of these strategies can engage stakeholders (the research community, funding agencies, business, civil society, regional and local governments) in broad consultations that will help building a common vision of the future and facilitate coordination within the innovation system.*' (OECD, 2014)

These strategies may have different scopes of action, such as the geographic focus (supranational-national-regional-local), the economic level (overall, industries-based, technologies-based), the impact level (overall, scientific, technological, economic, social), sources (supply-oriented, demand-oriented, or both), timeframe (based on past experiences or future expectations), and other features. In line with the second characteristic mentioned by the OECD, the STI strategies come to prioritize some activities over others, either explicitly or implicitly, with this non-neutral approach being called 'directionality' (as has been presented in previous sections). Directionality has been regarded by scholars of the field such as Mariana Mazzucato as one of the two main characteristics of innovation policy, affirming that 'Innovation has not only a rate but also a direction' (Mazzucato, 2018) that allows governments to develop innovation-led growth (Mazzucato, 2015) which is 'smarter', 'inclusive', and 'sustainable'. At the same time, directionality has been indicated as one of the potential failures that drive the most recent feature of innovation policy, Transformative Change (Weber, Rohracher, 2012).

In this sense, directionality has often been linked with the notion of collective priorities by Schot and Steinmuller in their review of the frameworks of innovation policy, saying that 'The transformative change frame takes the question of direction as a starting point and requires a process for setting collective priorities' (Schot, Steinmueller, 2018), as well as by Chaminade *et al.* when they said 'Directionality refers to the need to articulate collective priorities and the direction of change.' (Chaminade et al., 2018). This definition of the collective priorities may be either based on the selection process for the areas to be addressed by specific STI strategies, or in the definition of the aims and expected outputs of these strategies. Furthermore, the relationships and definitions of the 'directionality' concept are broad enough to aim for multiple target dimensions of interest, such as priorities between areas, sectors, levels, processes, populations, or organizations, among others.

As presented by Daimer *et al.*, in the context of the *normative turn*, challenge-driven innovation activities should be characterized for displaying features such as socio-technical, systemic, transition-oriented, experimental, *glocal*, transdisciplinary, and participatory elements, in order to fulfill the new requirements of these orientations (Daimer et al., 2012). In this scenario, the connections between NPCs for STI – as a device to implement governance for STI – and STI strategies are multiple, since as highlighted by Borowiechi and Paunov, from the evidence of the RESGOV database, 74% of OECD countries considered in the survey that have a council and answer positively to the question regarding the participation of the council in developing national strategic priorities.[5] Furthermore, in this subset of countries, these documents may have a specific focus to address the current issues of directionality:

> *'Science, technology, and innovation (STI) strategies or plans are in place in most countries (33 of 35, 94%). These commonly define STI strategies to address major societal challenges (30 of 33, 91%). Key themes include sustainable growth, health, and effi-*

Table 1. **Evidence of directionality in national STI strategies or plans for OECD countries**

2.6. Does the national STI strategy or plan address any of the following priorities? Specify whether another more dedicated strategy (e.g. a specific plan) covers these topics?*	Number of positive answers	Percentage of the respondents
a) Specific themes and/or societal challenges (e.g. Industry 4.0; 'green innovation'; health; environment; demographic change and wellbeing; efficient energy; climate action)	30	86%
a_2) Demographic change (i.e. ageing populations, etc.)	14	40%
a_3) Digital economy (e.g. big data, digitalisation, industry 4.0)	25	71%
a_4) Green economy (e.g. natural resources, energy, environment, climate change)	27	77%
a_5) Health (e.g. Bioeconomy, life science)	28	80%
a_6) Mobility (e.g. transport, smart integrated transport systems, e-mobility)	16	46%
a_7) Smart cities (e.g. sustainable urban systems urban development)	16	46%
b) Specific scientific research, technologies and economic fields (e.g. ICT; nanotechnologies; biotechnology)	31	89%
b_2) Agriculture and agricultural technologies	18	51%
b_3) Energy and energy technologies (e.g. energy storage, environmental technologies)	27	77%
b_4) Health and life sciences (e.g. biotechnology, medical technologies)	29	83%
b_5) ICT (e.g. big data, digital platforms, data privacy)	29	83%
b_6) Nanotechnology and advanced manufacturing (e.g. robotics, autonomous systems)	24	69%
c) Specific regions (e.g. smart specialisation strategies)	23	66%
d) Supranational or transnational objectives set by transnational institutions (for instance related to European Horizon 2020)	20	57%

* Part of the answers to the question 2.6 of the REGOV questionnaire: '2.6. Does the national STI strategy or plan address any of the following priorities? Specify if another more dedicated strategy (e.g. a specific plan) covers these topics. Please refer to the main STI strategy. If additional strategies address the following issues, please provide further information on them. a) Societal challenges a_1) Which priorities b) Scientific research, technologies, and economic fields b_1) Which priorities c) Regions c_1) Which priorities and regions d) Supranational or transnational objectives d_1) Which priorities e) Quantitative targets for monitoring and evaluation

Source: OECD RESGOV DATABASE. https://stip.oecd.org/resgov/, accessed 02.09.2022.

[5] Broadly, the role of Councils in STI strategies for specific areas can help to cope with at least three of the transformational system failures defined by (Weber, Rohracher, 2012), 'directionality' in order to aim for a specific position of transformative change, 'policy coordination' regarding the alignment of efforts that governments can enact with their policies and instruments, and 'reflexivity' as the capacity to monitor and assess the development of the initiatives for transformative change.

cient transportation systems. STI strategies and plans also define specific scientific research, technologies or economic fields of national priority (31 of 33, 94%). In 23 of 32 countries (72%), STI strategies address specific sub-national priorities for specific federal states or regions, reflecting for EU member states and partner countries Smart Specialisation Strategies.' (Borowiecki, Paunov, 2018).

More detailed information of the responses is available in Table 1.

Methodology and Case Selection

In this section, the first subsection will illustrate the methodology followed for this research, and the next two subsections will present each of the selected NPC cases and their roles in the development of the specific STI strategy.

Methodology

This methodology coincides with that of Yin, following the COSMOS Corporation vision of a research design about an organization and a source for data collection from individuals (how the organization works) and the organization (organization outcomes) (Yin, 2003). The case selection process follows a *polar types* criteria (Eisenhardt, Graebner, 2007), also known as *two-tailed* (Yin, 2003) or *diverse* (Seawright, Gerring, 2008) criteria, by using the differences among the subjects to identify their features. This is based on the empirical results obtained from the iNPC index (Cevallos, Merino-Moreno, 2020), selecting one *strong* council with a high level of potential according to their structural capacities and one *agile* council with a low level of potential due to their structural capacities complying with the extreme versions of this type of organizations for STI.

The selected councils are the National Council of Innovation for Development (CNID) of the Republic of Chile as a representative of a potential[6] transformative council, and the Advisory Council for Science, Technology and Innovation (CACTI) of the Kingdom of Spain as a representative of a potential agile council. To compare these councils, their information is synoptically consolidated in Table 2. The development of these strategies coincided in both cases with governments with a center-left political orientation. Furthermore, the STI strategies selected are different in terms of the area under consideration but also in their scope of action. Respectively, these are local initiatives in Chile for an initially endemic challenge that has the potential to position the country on the international stage, and global in the case of Spain for a widespread opportunity that is being tackled by several countries around the globe. This strategy selection process followed a selection based on their representativeness for the STI Strategy for Natural Disasters Resilience (NDR) of Chile, and also for the unique case of the STI Strategy for Artificial Intelligence (AI) of Spain. For comparison purposes, while it would have been ideal to review the same strategy in each country[7], due to the timing, the idiosyncratic nature of this definition, and the value embedded in the comparison of these two extreme types of councils, different sectoral strategies were considered. This information is summarized in Table 3.

The data collection methodology used to gather the presented information comprises primary data obtained in individual semi-structured recorded interviews of CNID and CACTI councilors (more information in Table 2) regarding the general operation of NPCs and directionality, and in some cases addressing the role of the NPC regarding the specific strategy explicitly. These interviews were conducted between the years 2018 and 2019 and were complemented by secondary data reviewed from relevant documentation such as laws, decrees, and reports regarding each of the councils. The interviews consisted of ten councilors from CNID and five from CACTI, and were performed in Santiago de Chile and Madrid (more information in Table 4).[8] The choice regarding the councilors as a primary source is based on the information they have as part of the organization and the fact they are familiar with its internal operation and also have a background as part of the community sensitive to the outcomes and products of the Council. These insights make the councilors the ideal sources for the aims of this research, illustrating the NPCs' role in the process of a specific strategy and comparing the policy options derived from different organizational settings.

The Chilean Council of Innovation for Development and the STI Strategy for Natural Disasters Resilience

The Chilean Council of Innovation for Development (CNID)[9] was established in the year 2005 by Presidential Decree as an advisory council for the Chilean presidency.[10] Since then it has had five clearly defined stages of development with unique compositions and mandates. The first stage lasted only for a few months and set the organizational and conceptual basis for the

[6] The notion of 'potential' rests on the fact that the classification is based on empirically observable structural characteristics and not on the councils' actual performance, since there are no obvious strategies to measure their results.

[7] At document closing time, the Presidency of the Republic of Chile mandated the New Ministry of Science, Technology, Knowledge, and Innovation to have a discussion on the Artificial Intelligence STI Strategy, following a very similar path as that demonstrated by Spain.

[8] The design of the data collection process did not force the interviews to be held in capital cities, but due to the availability of the councilors, they ended up occurring there.

[9] Formerly Innovation for Competitiveness (CNIC) until 2014.

[10] Ministerio de Hacienda de la República de Chile, 2005. *Decreto n°1408: Crea comision asesora presidencial consejo de innovacion para la competitividad.* https://vlex.cl/vid/asesora-presidencial-competitividad-241643950, accessed 15.04.2022.

Table 2. **Comparison of the Structure of CNID and CACTI**

Chilean Council of Innovation for Development (CNID)			
Executive Capacity			
Council´s Role	Joint Planning	Coordination	Advice
Executive´s Role	Involvement of the Top Level	Involvement of the Ministries Level	Involvement of the Upper Management Level
Coordinative Capacity			
Composition	Government Officials (4) Ministers of Finance, Economy, Education, and Agriculture, or their representatives.	Outstanding Personalities (14) One of them is appointed President of the Council by the government with partial dedication.	Representatives of Society (Stakeholders) (2) One vice- president for research from the universities and one expert in vocational training from the Vocational Schools, both in consultation with the Ministry of Economy.
Resources	Funding for Institutionalization	Funding for Studies	Funding for Logistics
Spanish Advisory Council for Science, Technology and Innovation (CACTI)			
Executive Capacity			
Council´s Role	Joint Planning	Coordination	Advice
Executive´s Role	Involvement of the Top Level	Involvement of the Ministries Level	Involvement of the Upper Management Level
Coordinative Capacity			
Composition	Government Officials	Outstanding Personalities (10) One of them is elected President of the Council by the councilors	Representatives of Society (Stakeholders) (4) Two representatives of the central business confederations and two of the main Unions.
Resources	Funding for Institutionalization	Funding for Studies	Funding for Logistics
Source: authors.			

Council starting in March 2006 with the newly elected government. In this first complete presidential term, the Council had two stages (2006-2008 and 2008-2010) characterized by the definition of a National Strategy for STI and strategical selectivity.[11]

The next phase (2010-2014) coincided with a new government with a different political orientation, and this was a time of revisionism and future thinking. The final stage of CNID spans between the years 2014 and 2017, again under a different coalition government (the same one that established CNIC), when it became a Council for Development rather than Competitiveness, with the purpose of explicitly social innovation for national welfare. In the year 2018, a new governmental institutionalization for STI was approved, under the same administration as in 2010-14, leaving the Council partially on hold until the new organizations were to be deployed in the year 2020.

CNID has a mandate over the policy domains of science, technology, and innovation, aiming to encompass efforts toward these goals. The Executive Power is involved at the highest level in leading the Council, not by participating in the discussions but rather by defining the overarching goals and expected advice from the Council. The presidency scheduled a few meetings with the whole Council during the presidential term and mostly developed a fluid connection with the President of the Council, who was appointed and trusted by the government with access to its capacities and political vision. The role of the Council is to advise the Presidency, and its aims are divided among specific products (such as reports on relevant issues) and the creation of a social currency that goes beyond the government and the Council concerning themes of interest. CNID is composed of ministries, outstanding personalities from the fields of science, technology, innovation, education, and socially oriented NGOs, representatives of stakeholders, and finally government agency chair-people as guests. This composition of the Council is supported by a Secretariat with funding to provide administrative and professional support, and also with a mandate to command a few external studies per year.

Since its reconfiguration in 2014, the CNID received a Presidential mandate to discuss a new regime for STI broadly. Among the definitions of the strategical agenda, the Commission highlighted the need to 'Concentrate efforts in prioritized areas' and suggested that three areas were prioritized during that presidential term.[12] This was a shift compared to policy in recent

[11] For this definition process, CNID (at that time CNIC) hired the assistance of the Boston Consulting Group (BCG). After the delivery of the BCG reports, including an iteration process and involvement of CNIC, CNIC started the implementation of this selectivity as a National Cluster Policy (Benavente et al., 2017). This strategy of introducing neutrality of interests due to the incorporation of an external party was followed by other Latin American countries (Fernandez-Arias, Stein, 2014). However, this process did not last long because of the end of the presidential term and the change in government, with a new government focused on neutral policies (*Ibíd.*). Despite the long-term strategic perspective that is intended to be given to these areas, the role of different administrations' political orientations do not seem innocuous in these definitions.

[12] http://www.sur-austral.cl/comision-presidencial-ciencia-para-el-desarrollo-de-chile-entrega-informe-un-sueno-compartido-para-el-futuro-de-chile/, accessed 15.04.2022.

years, since a 2017 study on Chilean national investment in STI highlighted the prior ten-year period, in which government spending had a neutral approach of 70% on average, with the remainder mainly associated with a sectoral focus in lieu of a strategical one (Balbontín et al., 2018). For analytical purposes, in the remainder of this document, we will focus only on the Resilience for Natural Disasters proposal due to its uniqueness and the relevance of the field for the country, which has highlighted its position on the subject as a Natural Laboratory (NL) (Guridi et al., 2020).

For the timeframe relevant to defining the strategy, the CNID was located on the strategical level of the public organizations for STI policy. At the same time, the Education and Economy ministries mainly occupied the political level. Finally, the operational level of STI policy encompassed a research agency, *Comisión Nacional de Investigación Científica y Tecnológica (National Commission for Scientific and Technological Research, CONICYT)*, an innovation agency, *Corporación de Fomento de la Producción (Production Development Corporation, CORFO)*, a myriad of independent public research and/or technological institutes, and several autonomous public universities (considerably fewer than private universities), largely covering the regional gradient and with a slight concentration on the metropolitan area (as the population is also concentrated).

The Spanish Advisory Council for Science, Technology, and Innovation and the STI Strategy for Artificial Intelligence

The Spanish Advisory Council for Science and Technology (CACT) was established according to the Law for the Promotion and General Coordination of Scientific and Technical Research.[13] In this law well over thirty years ago, the Spanish state acknowledged the relevance of the bond with stakeholders for science and technology, specifically those from the private sector and scientific communities, and their work toward the socially desirable development of their activities. Regarding the composition of CACT, as specified in the law it was first chaired by the Minister of Industry and Energy and then by the Minister of Science and Technology, and as defined by successive modifications in Royal Decrees[14], councilors from public and private research organizations, innovative enterprises, business confederations, unions, and government officials. The studied Spanish Advisory Council for Science, Technology, and Innovation[15] was considered in the Law for Science, Technology, and Innovation promulgated in 2011.[16] This law crystallized the position of the Council[17], with the possibility provided for them to intervene in the strategical process of STI and act as a bridge for society to influence these policy domains (Díez-Bueso, 2013).

CACTI has been mandated to coordinate the policy domains of science, technology, and innovation. The role of the government is at a low commitment level, acting as a counterpart for the Council by giving it inputs and receiving their outputs. The hierarchy within the Council is defined by the conforming councilors, who elect a president in charge of coordination with the executive branch and a vice-president to provide support. The aims of the Council mainly concern carrying out their advisory role on specific products, such as the National Plan for Research and Innovation, the National STI Strategy, specific calls, and other policies and instruments. The official composition of the Council lacks governmental representatives and guests, since it exclusively considers outstanding personalities and stakeholders' representatives of business and unions. The Council does not have administrative and professional support but has the resources of the Ministry if needed since, in practice, a government official acts as the secretary of the council.

The Spanish STI strategy designed for the 2013-2020 period stressed the importance of being aligned with European STI efforts, specifically by supporting the objectives of the Innovation Union, the European Research Area, and the Framework Program Horizon 2020. This strategy defined as one of its objectives the 'STI support towards the societal challenges', outlining eight grand challenges that encompass research and innovation and intersectoral and multidisciplinary collaboration to receive societal returns in the medium and long term.[18] Coincidently, Artificial Intelligence has also been in the sights of the European Commission[19], highlighting it as one of the most strategic technologies of the century, and recognizing the need for a coordinated approach among European nations to face its challenges (European Commission, 2018).

[13] Jefatura del Estado. Ley 13/1986, de 14 de abril, de Fomento y Coordinación General de la Investigación Científica y Técnica. 1986 Apr 14. https://www.boe.es/buscar/doc.php?id=BOE-A-1986-9479, accessed 15.04.2022.

[14] Ministerio de Industria y Energia del Gobierno de España, 1987. *Real Decreto 834/1987, de 19 de junio, de regulación del Consejo Asesor para la Ciencia y la Tecnología* (https://www.boe.es/eli/es/rd/1987/06/19/834, accessed 15.04.2022); Ministerio de Industria y Energia del Gobierno de España, 1990. *Real Decreto 1213/1990, de 28 de septiembre, por el que se modifica la composición del Consejo Asesor para la Ciencia y la Tecnología* (https://www.boe.es/buscar/doc.php?id=BOE-A-1990-24507, accessed 15.04.2022); Ministerio de Ciencia y Tecnologia del Gobierno de España, 2001. *Real Decreto 413/2001, de 20 de abril, por el que se regula el Consejo Asesor para la Ciencia y la Tecnología* (https://www.boe.es/buscar/doc.php?id=BOE-A-2001-7796, accessed 15.04.2022).

[15] The concept of *innovation* was added to the Council definitions on this Law.

[16] Jefatura del Estado, 2011. *Ley 14/2011, de 1 de junio, de la Ciencia, la Tecnología y la Innovación. https://www.boe.es/buscar/act.php?id=BOE-A-2011-9617,* accessed 15.04.2022.

[17] Regarding the position of the former Council considered in the previous institutional arrangements.

[18] Ministerio de Economia y Competitividad del Gobierno de España, 2013. *Estrategia Española de Ciencia y Tecnologia y de Innovacion 2013-2020.* https://www.ciencia.gob.es/Estrategias-y-Planes/Estrategias/Estrategia-Espanola-de-Ciencia-Tecnologia-e-Innovacion-2021-2027.html;jsessionid=E9804D291B82B99A578A80C845349989.2, accessed 15.04.2022.

[19] This is part of the complexity faced in the STI policy domains in EU countries and attests to the need for coordination derived from this (Magro et al., 2014).

Table 3. **Case Studies**

Country	Chile	Spain
Type of Council	Strong	Agile
Council	CNID	CACTI
STI Strategy	Natural Disaster Resilience	Artificial Intelligence
STI Activities	Specific activities	
Scope	National	
Problem	Supply, Demand and Interactions	
Source	Top-Down	
Aims	Proposal of a new policy	
Position	Open	
Power	Symmetric relationships	
Temporality	Limited period	

Source: authors, partly following the scheme proposed by (Dutrenit et al., 2017) for dialogue processes about STI.

For the time in which the aforementioned strategy was defined, the strategic and political levels of the STI policy were blurred, with the renewed Ministry of Science, Innovation, and Universities acting as a *primus inter pares* among the ministries and with a prominent role played by the Ministry of Economics, Industry, and Competitiveness. They received the advice of CACTI and coordinated the STI policy with another council, Consejo de Política Científica, Tecnológica y de Innovación (Council for Science, Technology and Innovation Policy). This council is not considered a National Policy Council for STI since it is has a national-regional focus. The high-level government officials and the officials who acted as representatives of each Autonomic Community participated. The operational level of the STI policy included an agency mainly oriented toward research and development, *Agencia Estatal para la Investigación (State Agency for Research)*, an agency focused primarily on innovation, *Centro para el Desarrollo Tecnológico Industrial (Center for Industrial Technological Development, CDTI)*, several public research and/or technological institutes mainly under the umbrella of *Consejo Superior de Investigaciones Científicas (Superior Council of Scientific Investigations, CSIC)*, and numerous independent public universities (considerably more than private universities).

Results

Following the qualitative methodology supported by the literature for this type of research and explained in the previous section, the results will be presented in three analytical pillars, each a subsection. The first aim is to shed light on the ideological positions of the councilors regarding directionality, which is a relevant input for the two subsections which are more directly related to the objectives of this document: first to illustrate the process of defining the strategies and then to compare their design processes. Finally, one subsection will summarize the topics with an overarching view.

Councilors' positions on directionality

To frame the object of study, the initial analysis involved getting acquainted with the councilors' positions on their ideological definitions regarding directionality. While more specific research could be developed on this subject alone, an initial distinction emerges on approaches to directionality, which remain political for the Chilean councilors but saw a more pragmatic logic of compliance-and-profiting for the Spanish councilors.

> *'I believe that the philosophy of having as a base that a Council will be able to determine 'the five most important things to do' is an incorrect approach and leads to entrenchment'.*
> Chilean Councillor #5

> *'We had a discussion in the context of the report about the state's plan (for STI). Indeed, one of the guidelines is to identify strategic lines, but we did not consider it a priority within the Council'.*
> Spanish Councillor #1

From the previous quotes, the Chilean councilor illustrates the position of some of their Council peers that were not convinced about the role that a council should have regarding directionality. Meanwhile, the Spanish councilor presents a new scenario, which is not necessarily choosing which sectors matter – considering the role of the Council – but may be among other levels of interest. In the next quotes, for the case of Chile, the feature of directionality emerges as a pos-

Table 4. **More information about the interviewed councillors**

Councillor	**Date of Interview**
CNIC/CNID, Chile	
#1	07 Aug 2018
#2	13 Aug 2018
#3	17 Aug 2018
#4	21 Aug 2018
#5	22 Aug 2018
#6	21 Dec 2018
#7	26 Dec 2018
#8	26 Dec 2018
#9	27 Dec 2018
#10	05 Jul 2019
CACTI, Spain	
#1	10 Oct 2018
#2	26 Feb 2019
#3	15 Mar 2019
#4	08 Apr 2019
#5	24 Apr 2019

Note: In case of CNIC/CNID all interviews are taken at Santiago, Chile; and in case of CACTI – in Madrid, Spain.

Source: authors.

sibility with the existence of the Council, albeit in a dilettante approach. At the same time, for Spain it appears to be strongly related to the supra-order of the European Commission regarding the STI matters and its political and economic influx and incentives.

> *'Before the existence of the Council, prior to 2004, in the public discussion the possibility to propose strategical areas was vetoed, it had no chance (…) despite some particular projects, when it was raised to some degree of public discussion, you encountered really strong reactions. (…) Basically it (the Council) came to legitimize one governmental choice about those areas, (…) the logic was, well, how the citizens define this area prioritization'.*
> Chilean Councillor #3

> *'What is sought (in Spain) is to bring as much as possible of what Europe is willing to put in more quantity, therefore their elections are always telling us they are mediated by what Europe has said'.*
> Spanish Councillor #5

However, despite their differences, the evidence gathered for this pillar from both councils' positions seem to agree on the role of the council as a consensus device regarding the STI policy, where stakeholder perspectives were discussed and modulated, giving a stamp of legitimacy for the political process related to these matters.

The role of the council in the strategy selection process

Regarding the selection process, for the Chilean case, to comply with the suggestion made by the Commission in 2015 – mentioned in the previous section – the Presidency mandated CNID to propose agendas regarding two highly sensitive issues for Chile: Natural Disaster Resilience and Hydric Resource Sustainability. On the other hand, the Minister for the Economy attended one of the meetings of the Council to ask for a proposal regarding Ports and Tourism. The Mining Ministry also asked the Council to continue with a proposal developed by social organizations and business confederations regarding mining. In Spain, on the other hand, following the roadmap defined by the European Commission to establish a new common platform (i.e., the European AI Alliance), as a member country the council was requested to develop its national strategy for Artificial Intelligence before July 2018.

> *'Once the report about science and development was handed to the President, in that exact same act she acknowledged that there are two big issues that concern us as a country, and we are interested in what science and technology have to say on the subject. The themes of Hydric Resources and of Natural Disasters'.*
> Chilean Councilor #10

> *'The Ministry has the commitment, I believe for June or July (2019), to present Europe a strategy for Artificial Intelligence for the country as a member state of the Union. (…) A first document was written and they asked for CACTI's opinion, I do not know if others' opinions were asked'.*
> Spanish Councilor #4

From the dispositions presented in this pillar, it became clear that despite being part of previous discussions that addressed the topics defined by both governments to enact the STI strategies, both councils were not directly part of the definitions, nor did they even engage in the final conversations about the shortlist of themes to prioritize in the domain of STI policy. This secondary level of involvement raises questions about the expected versus real design of the councils' structure and operation, and how the potential benefits in the strategical level of STI policy that these organizations were supposed to bring are exploited.

Council's role in the design process of the strategy

The Chilean CNID broadly convened society to participate in a new commission to develop a National Strategy of STI for Resilience for Natural Disasters (CREDEN). This strategy could be initially labeled as *defensive* since Chile is the OECD country most exposed to natural disasters and one of the most affected nations in terms of casualties and loss of material resources, but their purpose is to use this exposure as a source for innovation. The commission was divided into a central committee and four subcommittees. The initiative was championed by a councilor of the CNID, who worked for several months and delivered a final report by the end of 2016.[20] The document comprised the strategy, policy, and instruments to implement the defined efforts, as well as the definition of the required budget to be used to implement the strategy.

> *'The commission about natural disasters (…) had an ample discussion, because it is a particular challenge for Chile. (…) In this case, what was heavily employed was the science involved in this regard; because for a big part of the (previous versions of) Innovation Councils the science portion was mainly about natural sciences or engineering, but that I remember the social sciences were not that present (…) however they led the discussion regarding natural disasters, there were many scientists from that background, and also governmental offices (…) it was multidisciplinary, multi-technical'.*
> Chilean Councilor #7

The Spanish STI Strategy for Artificial Intelligence was developed by the Working Group on Artificial Intelligence (Grupo de Trabajo en Inteligencia Artificial, GTIA) appointed by the General Secretariat of Science

[20] Comisión Nacional Para La Resiliencia Frente A Desastres De Origen Natural (CREDEN), 2016. *Hacia un Chile Resiliente frente a Desastres: Una Oportunidad.* Santiago de Chile. https://www.cr2.cl/wp-content/uploads/2017/01/INFORME-DESASTRES-NATURALES.pdf, Accessed 03.09.2022..

Policy Coordination of the Ministry of Science, Innovation, and Universities, outlining the strategic priorities on the subject to be implemented with specific instruments to be defined in the STI annual plans.[21] According to the report, the comments provided by CACTI were considered in developing the document for this strategy. Resource constraints were indicated as the main restriction limiting a higher degree of involvement in the process.

'As a councilor, (…) I contribute to this, but who has to do the charts is not me, because it has to do with some minimal conditions (…) It does not exist, each one collaborates according to their personal inputs (…) we contribute with personal experience but without a structure, so it is really difficult to work. Because you are assessing artificial intelligence documents and, if you do not give me a few days, then I do not have any clue'.

Spanish Councilor #3

'If I have a doubt related to artificial intelligence, given that I am not a specialist, I have plenty of resources to ask experts (…) about their vision. The same thing happens with the rest of the councilors'.

Spanish Councilor #2

'We could not make a document about artificial intelligence because, truth be told, only three or four members of the Council had the capacities and time to form an opinion. (…) It is right that the Ministry did this because we would not have the capacity since we do not have a Secretariat or anything to catch all those people'.

Spanish Councilor #4

From this pillar, coordination capacity differences emerge as a distinctive feature of the councils' involvement in designing their strategies. The broadly understood deployment of resources on the councils or in other organizations related to STI policy (such as ministries or agencies) may have a particular effect on processes developed by these councils, such as the broadness of the consultation process with outsider stakeholders or the depth in which the strategies are questioned in a timely way.

Summary

According to the testimonies gathered, the *ex-ante* position for the councilors regarding directionality was not a consensus. The reasons concerning the partial refusal to select areas for their strategical development mainly had to do with the uncertainty involved in this forecasting exercise, and the need for more resources – broadly understood – to develop such decisions. However, if directionality was a mandate of the Council or, even better, was partially or fully defined in other governmental bodies, and therefore their participation was an *ex-post* position, the councilors were in place to support the predefined aims. In other words, it seems that in this context, the councilors preferred to enhance definitions rather than making them. This suggests that the issues of responsibility and resources are highly connected with the councils' capacities to comfortably work on the area of directionality.

For the cases of interest, the process of the councils' participation in directionality efforts could be illustrated according to Figure 1. From this figure, the depicted process for the Spanish Council appears more complex than the process of the Chilean Council. In the same fashion, the processes developed by the Chilean Council seem deeper (championing the process) than the processes of the Spanish Council (exercising their advisory role) given that in the latter, the Ministry complements some of the activities developed by the Council, specifically regarding the relationship with stakeholder communities. In sum, while in Chile the mandate of the specific strategy came directly from the Presidency, in Spain the mandate was first supranational, and then the Presidency identified the best institutional way to address it. Furthermore, for the Chilean case, the design of the strategy was broadly developed by the council. In Spain, the Ministry had to perform that task, and after that a consultation process involved the council.

The roles played by each of the councils also seem somehow related to the expectations of their design, regarding their executive and coordinative capacity, and specifically the resources involved. The latter is a controversial issue since it may seem enough for some councilors or insufficient for others, the questioning of what is an appropriate level of resources for the definition of strategies that are aimed to shape the future of a country in a given direction. However, these inquiries help stakeholders determine whether their actions meet contemporary STI policy requirements and the proper scope of activity.

Final Reflections

Following the rationale of increasing demands for STI policy depicted in the introduction of this document, the obtained results unpack the issue of *the process* and the actual role of governments, which is complementary to the theoretical approach depicted by (Boon, Edler, 2018), and that of the stakeholders. Despite the fact that National Policy Councils seem to be aligned with the notion of related communities' involvement in definitions regarding the directionality of efforts in STI policy, it does not seem evident that every NPC configuration will be suitable for developing this task while complying with the mandates. On the other hand, leaving this process as duties of the exclusive responsibility of the governmental departments jeop-

[21] https://www.cr2.cl/wp-content/uploads/2017/01/INFORME-DESASTRES-NATURALES.pdf, accessed 14.08.2022.

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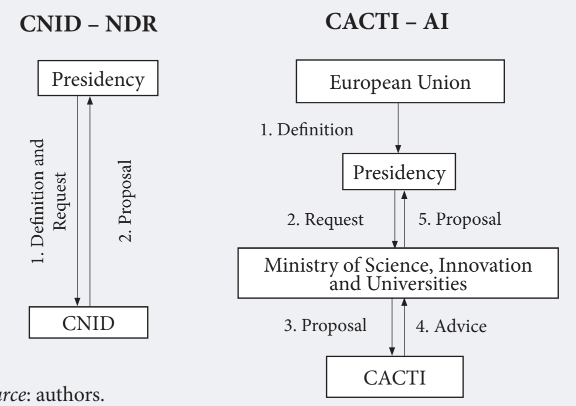
Figure 1. **Comparison of CNID and CACTI Mandate of STI Strategy**



Source: authors.

Expectedly by design, both the resources and the councils' role were indicated as the main reasons for the difference in the involvement of the two studied councils. However, this difference draws attention to the reality of the prescriptive nature of STI policy scholarship highlighted by (Flanagan, Uyarra, 2016). In this context, the directionality issues characteristic of the framework of transformational change should also consider the specific features of the councils mandated to develop certain tasks. Furthermore, the implications of these decisions remain an issue since the *raison d'etre* of the councils seems strongly related to their strategical capacities and, therefore, to the general directionality that these organizations can imprint upon discussions about STI policy. This approach questions the links between the councils and the *normative turn*, how they relate to their mandates and STI priorities. Do councils foster and enhance discussions about normativity and directionality? Are the councils focused on pre-made definitions regarding these subjects? Or, is there a continuum in which every country has to find and define their position?

The nature of these discussions is also affected by the overall STI configuration of organizations and their relations, following the studies (Lepori, Reale, 2019; Breznitz et al., 2018; Cruz-Castro et al., 2020) on the operational level and (Cevallos, Merino-Moreno, 2020) on the strategical level. Bearing in mind the potential configurations of the political level as well, i.e., which ministry or ministries will be in charge of the STI policy domain(s), STI policy also faces the *puzzle of organizations*. This notion calls into question the organizational and institutional setting and how the different types for each of these organizations and relationships raise a more difficult challenge to tackle the aforementioned demands, or positively, producing a multiplicity of potential answers due to the different configurations of organizations and their types.

In the process of this research, several avenues were found that could be complemented by future studies. Regarding the specific object of the councils, addressing how these organizations are formed more specifically (on an individual level), equipped, and assessed remains a challenge for both academia and governments. Moreover, regarding the relationship between councils and their activities, the ideological approach to directionality seems to deserve more scholarly attention, despite the gained momentum in the policy-making arena. To define how to cope with neutrality or disbelief among councilors is a question that appears at the core of how strategic decisions are expected to be made. The role that the councils are expected to play in efforts aimed at directionality seems to depend upon agreements and positions that may not have the clarity needed to embark on great challenges and missions, such as the STI policy seems to require. Therefore, the definitions surrounding directionality, including their rationales and implementers, remain a moving object, along with the roles that different actors have to play in this process (*who is in charge of what*). Finally, the assessment of directionality definitions appears to remain scarce. While there is much evidence on the will to make it happen and succeed in it, more research on the past results of these situations – and intermediate assessments for ongoing projects – would be necessary to address directionality and therefore partially support the framework of transformational change.

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The Dynamics of University-Industry Interactions in Peripheral Contexts: Evidence from Brazil

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Abstract

This research aims at addressing the factors that constrain the flow of knowledge between universities and industry when these players are embedded in peripheral contexts. A multiple-case study was carried out in order to describe and understand the limitations of universities as agents of innovation in peripheral ecosystems. Twenty-two semi-structured interviews were conducted with the coordinators of five Technological Innovation Centers (entities equivalent to TTO) of all Federal Institutes (five) located in the State of Minas Gerais, Brazil. The findings show that there are constraining elements associated with the socioeconomic environment (the lack of economic dynamism and low absorptive capacity at firms), with universities (a lack of infrastructure, resources, and available researchers) and intermediary agents (the lack of staff and institutional legitimacy). The observed conditions lead to challenges in fostering dense knowledge flows, thus perpetuating regional economic asymmetries and hindering the institutional evolution of academic institutions toward the notion of entrepreneurial universities. Our research contributes to literature by addressing in detail the limitations of universities in spurring dense innovation networks in laggard ecosystems. Instead, more complex co-evolutionary processes seem to be at play – and "silver bullet" policies are likely to offer disappointing results.

Keywords: knowledge flows, innovation ecosystems; entrepreneurial university; technology transfer; developing countries; Brazil; university-industry interactions

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Introduction

Innovation and technology transfer have become a priority for universities (Min et al., 2019; Stankevičienė et al., 2017). This focus on knowledge transfer has stemmed from top-down initiatives and has been driven by policymakers who encourage universities to take a proactive stance regarding national and regional economic development (Etzkowitz, 1998). In this sense, these institutions have adopted a dynamic system approach whose main feature is knowledge transfer through activities involving multifaceted interactions with other agents (Schaeffer et al., 2021). This gave rise to institutional changes aimed at encouraging closer connections between universities and industry actors (Fischer et al., 2019).

However, empirical exercises usually analyze their impacts in fairly munificent contexts with a strong presence of complementary actors, a well-established culture of innovation, high economic dynamism, and strong technological activity (Guerrero, Urbano, 2017). Although such studies draw attention to possible outlines, they can hardly be generalized (Sandström et al., 2018). Peripheral regions require a broader concept of innovation systems, especially regarding their actors (Etzkowitz et al., 2005). For example, in addition to what is commonly understood, the university concept also includes contributions to the emerging demands of society that lie outside the scope of traditional technology transfer processes (Bonaccorsi, 2017).

Considering that regions respond differently to development policies – a function of their heterogenous specificities – there is no guarantee that a successful model in core economic hubs will have similar effects on or produce similar results in peripheral regions (Sánchez-Barrioluengo, Benneworth, 2019). Therefore, this research aims to addressing *the factors that constrain the flow of knowledge between universities and industry when these players are embedded in peripheral contexts*. Our inductive assessment focuses on universities in Brazil, where the typical traits of peripheral regions are largely predominant, and academia and industry evolved separately (Dalmarco et al., 2018). Brazil – like many other developing countries - faces serious difficulties in fostering better quality relationships between the market and academia (Fischer et al., 2019). Such challenges may be related to more basic economic determinants of innovative activity in the country and its regions.

Given the above, the empirical scope of this research includes all Federal Institutes of Education, Science and Technology located in the state of Minas Gerais and higher education members of the Federal Network for Professional and Technological Education, whose mission includes fostering local economic development. The results reveal limitations at the level of ecosystems, institutions, and intermediaries (TTOs). These findings contribute to deepening our knowledge on the specificities and limits to the entrepreneurial university concept in peripheral regions, especially with regard to knowledge flows and technology transfer processes.

The Role of Universities in the Dynamics of Local Ecosystems of Innovation: The Moderating Role of Context

Benefits accruing from the relationship involving a myriad of actors in the network dynamics of local ecosystems of innovation contribute to the development of new knowledge at universities and companies. Tacit and explicit knowledge are combined in this process, leading to the creation of new products and services (Oh et al., 2016). In this context, the role of universities is closely related to their ability to produce and transfer knowledge, especially through its commercialization, with the potential to drive economic development (Schaeffer et al., 2021). Often, this scientific knowledge spills over onto the market where technological change is rapid and systemic and companies are increasingly dependent upon outside expertise to promote innovation and improve performance (Fernandes et al., 2010).

As knowledge and technologies grow more complex, learning processes at companies depend upon establishing connections with different actors (Schaeffer et al., 2021). Universities become key partners in this context because they often occupy central positions in knowledge networks (Huggins et al., 2019; Brown, 2016; Kempton, 2019). Accordingly, the involvement of universities in such innovation networks provides greater openness and a more substantial flow of knowledge as existing relationships mature and become increasingly productive (Granstrand, Holgersson, 2020; Huggins et al., 2019). In their turn, universities also benefit from new ideas for research projects and access to external funding, which can increase research productivity (Schaeffer et al., 2021, Bonaccorsi, 2017; Fischer et al., 2018).

However, not all businesses or universities are able to take part in networks at various levels. Accordingly, this can likely restrain ecosystem evolution. In this context, universities with fewer resources and less absorptive capacity tend to focus on local linkages, while those with more resources and greater absorptive capacity are involved in broader, interregional networks, thus being able to connect with more diversified knowledge sources (Huggins et al., 2008).

Regional Dynamics and University-Industry Interactions

Peripheral regions are characterized by a lack of economic dynamism, especially when measured by the presence of industrial parks and large companies; low institutional density; scarce innovation culture; and low levels of absorptive capacity (Tödtling et al.

2011; Tödtling, Trippl, 2005). These characteristics have a negative impact upon the interaction between universities and companies, since the probability of companies collaborating is strongly related to company size, technological level, and R&D spending (Laursen, Salter, 2004). Likewise, the regional impact of university knowledge depends on internal corporate factors – including entrepreneurial culture – and external factors at the regional level over which universities have no control (Bonaccorsi, 2017; Sánchez-Barrioluengo, Benneworth, 2019).

Thus, the contextual features of regional contexts and their inherent institutional aspects are directly related not only to the companies' ability but also to companies' interest and desire to effectively engage in innovation networks. In this regard, universities' reputations and prestige affect their attractiveness as partners for industry cooperation (Laursen et al., 2011). Companies prefer to cooperate with top-tier universities, regardless of distance, rather than second-tier universities (Bonaccorsi, 2017). On the other hand, cognitive distance has proved to be a serious obstacle for such collaborations to take place (Todtling et al., 2011).

Universities located in peripheral regions might be limited because they experience difficulties attracting high profile research and teaching staff, which potentially results in lower quality cooperative efforts or in less ambitious undertakings. In turn, companies with high absorptive capacity seek universities with greater capacity and a more robust structure for the development of R&D (D'Este et al., 2013). Meanwhile, companies with low absorptive capacity seek partners that are within geographical proximity (D'Este et al., 2013; Laursen et al., 2011), but these relationships seldom involve long-term R&D collaborations oriented toward innovation (Bonaccorsi, 2017). Also, in these regions, low levels of infrastructural quality and industrialization limits the ability of universities to establish productive relationships with partners from industry (Tödtling, Trippl, 2005).

Along these lines, while prior research has shown that universities engaged in innovation networks play an important role in a region's innovation culture, such impacts are more prominent in regions with greater economic density (Bonaccorsi, 2017). Their effects are mild in regions without adequate learning and technological capabilities, where the productive system is mainly composed of small and medium-sized enterprises with low-growth trends and fragmented connections with external sources of knowledge (Huggins et al., 2019; Huggins et al., 2008).

Given the above, the role of universities as pivotal promoters of regional development in peripheral regions is questionable, considering that the success stories found in the literature are based on regions that are among the most innovative in the world (Huggins et al., 2019; Tödtling, Trippl, 2005). In this sense, the literature focused on regional development has placed the burden of development on the notion of entrepreneurial universities (Bonaccorsi, 2017). These conditions are bound to generate, at best, lackluster outcomes since regional development depends upon the combination of myriad complementary agents and contextual conditions.

Methodological Approach

A multiple-case study was carried out in order to describe and understand the limitations of universities as agents of innovation in peripheral ecosystems. The option of studying multiple cases, as proposed by Eisenhardt (1989), was motivated by the characteristics of the unit of analysis of this investigation, namely Federal Institutes, since they comprise several features of a university, offering higher education and conducting scientific research and outreach activities.

Twenty-two semi-structured interviews were held with the coordinators of five Technological Innovation Centers (entities equivalent to TTO) of all Federal Institutes (five) located in the State of Minas Gerais, Brazil, with at least one researcher from each institute who was somehow related to the TTO, especially regarding intellectual property protection and technology transfer. Furthermore, the interviews were conducted with representatives of companies that had interacted with the TTOs. The surveys were carried out between October 2019 and October 2020. Other techniques were used during case studies to triangulate information (Eisenhardt, 1989; Yin, 2003). These involved direct observations and secondary data on technology transfer activity and contextual features of local economic environments. Table 1 shows that over 16 hours were devoted to the interviews, which were recorded, transcribed, and analyzed.

The transcribed data were used for content analysis based on the analytical categories in the respective interview protocols, defined *ex ante* and supported by dedicated literature (Eisenhardt, 1989; Yin, 2003). This process provided insights into defining the three analytical dimensions – local ecosystem, university research structure, and intermediaries. Ecosystem and university research structure were frequently cited in the interviews with the TTO coordinators, researchers, and company representatives, while TTO structure was strongly perceived in the interviews with their coordinators. The definition of these dimensions is shown in Table 2.

Research Setting

Considering that Brazil is a country of continental dimensions, many particularities can be found in its different regions. There are, therefore, regions with greater economic dynamism and greater capacity to absorb knowledge, such as São Paulo, where leading innovation ecosystems are located. These regions feature a number of successful cases in university-industry relationships (Schaeffer et al., 2021; Fischer et al.,

Table 1. **Interviewees by Institute and Segment**

Interviewees	Federal institute										Total	
	FI_1		FI_2		FI_3		FI_4		FI_5			
	Int	T**	Int	T**	Int	T**	Int	T**	Int	T**	Int	T**
TTO coordinator	1	57	1	52	1	80	1	*	1	130	5	319
TTO ex-coordinator	—	—	1	45	—	—	—	—	—	—	1	45
Researcher	2	94	3	127	1	*	1	66	2	120	9	407
Company	2	30	2	76	1	72	1	41	1	31	7	250
Total	5	181	7	300	3	152	3	107	4	281	22	1021

*Interviews given in writing (not recorded); ** T= interview time in minutes.
Source: authors.

2018). On the other hand, most other regions across the country face a rather distinct economic reality.

Peripheral regions lack innovation-oriented productive structures and are highly dependent on small and medium-sized enterprises with low-growth trends and specialize in medium-low and low-tech activities. Innovation networks in these regions have fragmented connections, with few external sources of innovation which are also geographically dispersed. The definition of cases in this study is relevant due to the scope of the institutions studied in the State of Minas Gerais, which has regions with heterogeneous economic, social, cultural, and demographic features. Thus, although the cases are relatively concentrated – covering the North, Central, West, Southeast, and South regions of the state - they can offer valuable insights for other peripheral regions embedded in the context of developing economies. In turn, understanding the dynamics of academic-centered innovation in such areas can provide a clearer view of the role (and limits) of universities as pivotal promoters of regional development in peripheral regions.

The analysis centered on the three main outlined dimensions. The first refers to the (peripheral) local ecosystem in which academic institutions are embedded. It is based on the premise that central regions stand for more munificent and complex ecosystems, enjoying a considerable advantage over peripheral regions. The second relates to universities' research infrastructure. Thus, it is understood that a lack of resources and the unavailability of researchers directly influence the innovation process as well as the ability of universities to interact with external agents. Lastly, an analysis of the intermediary dimension was carried out, more specifically within the scope of the Technology Transfer Offices (TTO) of universities.

Ecosystem Analysis

In the analyzed peripheral ecosystems, companies find it more difficult to implement innovation management processes and to become innovative, mainly due to economic uncertainties and difficulties in terms of scarce human and financial resources. These regions usually lack economic dynamism, absorptive capabilities, innovation culture, and present a low density of complementary elements to foster the formation of knowledge networks.

Economic Dynamism

Laggard regions mostly feature productive structures with low levels of technological capabilities, often involved in traditional sectors (Tödtling, Trippl, 2005). In an attempt to circumvent these obstacles, universities have strived to design their internal innovation policies for technology prospecting by observing the economic frameworks of their respective regions; the level of social development in the region; the qualita-

Table 2. **Relationships between the Analyzed Dimensions and the Respective Sources**

Dimension	Related topics	Source - Literature	Interviews and other sources
Local Ecosystem	• Economic dynamism • Absorptive capacity • Innovation culture • Institutional density	(Bonaccorsi, 2017; Boschma, 2005; Cooke, 2005; Guerrero, Urbano, 2017; Tödtling, Trippl, 2005)	• Interview with TTO coordinators, researchers and company representatives • Economic and social data • Institutional Development Plan
University research infrastructure	• Rapport • Facilities and resources • Bureaucracy • Researchers	(Bonaccorsi, 2017; Fischer et al., 2018; Huggins et al., 2019)	• Interview with TTO coordinators, researchers and company • Institutional Innovation Policy
Intermediaries – TTO	• Human Resources • IP Protection and Technology Transfer	(Hayter et al., 2020; Siegel, Wright, 2015)	• Interview with TTO coordinators and researchers • Institutional Innovation Policy

Source: authors.

tive analysis of the level of technological, industrial, and social development of the local economy; the compatibility between the technological demand of the local economy and the institution's expertise; and the possibilities of developing projects in line with the areas of expertise and operation of the innovation hubs. Qualitative data from our research revealed that this socioeconomic environment affects the capacity for integration between universities and the productive environment. This is in line with the perspective that the innovation context differs for a university in a less industrialized region compared to the ecosystem associated with a comparable university in a large metropolitan area (Siegel, Wright, 2015).

As the Federal Institutes operate in economically disadvantaged regions that face different types of problems such as unemployment, poor infrastructural conditions, and a lack of economic dynamism, a research agenda aimed at tackling such problems is required – thus dealing with a much more pressing and urgent agenda than fostering the formation of innovation networks. Corroborating this statement, the TTO2 former coordinator reports that the institution is located in a poor region with sanitation and industrial problems. "If, for example, the institutes acted decisively to truly tackle the problems of those societies and brought them inside the institute in order to solve them, it would be much more efficient" (TTO2 former coordinator). However, such alignment conditions often conflict with the research goals and capabilities of scientists.

Absorptive Capacity

Peripheral regions are mainly characterized by the predominant presence of micro and small enterprises and/or companies with a lack of innovation culture. These organizations are limited in their capacity to absorb complementary knowledge from external sources. This limitation concerns both the acquisition and assimilation of knowledge and the ability to transform and exploit it. Thus, these companies are unable to identify which kinds of knowledge can be absorbed or combined with their own expertise to create new technological opportunities. The effects of such a cognitive mismatch were often mentioned by the interviewees, whether TTO coordinators, researchers, or company representatives, following patterns reported in prior assessments (Crescenzi et al., 2017).

The TTO2 coordinator stresses that many companies have technological capabilities that are distant from those of the Federal Institutes. While this creates possibilities for partnerships dealing with issues that the company is unable to solve internally, the transfer of new technologies and even the identification of economic opportunities is constrained by this cognitive distance. Similarly, the TTO3 coordinator states that the university researchers can only develop research up to a certain point, being unable to engage in activities such as field testing, depending on the area or type of product. Hence, although there is the possibility of complementarity with reasonable cognitive distance, the low absorptive capacity discourages both companies and universities from establishing links in a context of innovation (Boschma, 2005; D'Este et al., 2013).

Another aspect related to cognitive distance concerns researcher training. In order to reduce this distance and adapt to the companies' demands, researchers might have to change their line of research, an issue that generates conflict with the autonomy of scientists. One TTO coordinator perceives that sometimes researchers get caught up in scientific endeavors and teaching activities, distancing themselves from market connections (TTO3 Coordinator). While this situation highlights an interest in generating economic development, it is likely to create animosity within the academic community (because it is attached to a loss of freedom in their scientific activities). On the other hand, it is at odds with how performance measurement is undertaken in the academic environment, favoring publications over the development of applied technologies oriented toward addressing market needs.

Innovation Culture

Innovation culture has a strong influence on issues related to university knowledge and learning, especially regarding innovation-related matters. Based on the interviews, it was noted that the TTO coordinators focused on the absence of innovation culture at both universities and companies. In this sense, one respondent states that in Brazil there is no culture of innovating in partnership with universities, with the exception of a few large companies and the pharmaceutical sphere where it occurs more frequently, "but if you look at other areas, it is something very incipient in the country" (TTO2 former coordinator). The (FI5) researcher emphasizes that the specific absence of an innovation culture at Brazilian companies hinders their relationship with universities, a point that was also reported by the coordinator from TTO5. This is corroborated by data from previous assessments and from the Brazilian Innovation Survey, which indicate that less than 4% of innovative companies in Brazil establish cooperative agreements with universities – and only half of that number consists of R&D-oriented projects (Fischer et al., 2019).

Institutional Density

Institutions play a key role in facilitating new opportunities for economic activity and innovation. However, peripheral regions normally lack effective local institutions and are not reached by institutions with a larger geographic scope, especially in countries as large as Brazil, thus creating localized institutional voids. In the case of the Federal Institutes, these conditions are expressed in the Institutional Development Plan of FI2, which states that of the nine micro-regions where the institution is present, only two have incubation programs. In addition, the (FI1) researcher stresses the difficulty in developing innovation activities in the region, since they are "in a region that is still poorly developed economically and socially". Hence, the provision of local-level support institutions that facilitate university-industry connections (Fischer et al., 2018) is often absent in such peripheral contexts.

Universities and Research Infrastructure

Research infrastructure involves both structural and organizational aspects. In this sense, the lack of resources, the limited availability of adequate laboratories for research, the lack of available researchers, excessive bureaucracy, and a lack of rapport with external agents are likely to restrict the integration of universities into an innovation network.

Lack of Rapport

Encouraging closer ties between universities and local companies is challenging. It is difficult to make managers embedded in peripheral ecosystems understand that research can be a driver to transform the company and their businesses. Data from the Brazilian Innovation Survey confirm these results. The share of firms developing joint R&D-oriented activities – instead of technical, training, and consulting forms of cooperation – has not increased despite the intensification of initiatives targeted at increasing the levels of university-industry collaboration in the country. More troubling is that the majority of companies involved in collaborative processes perceive Brazilian universities as agents of low relevance for their innovative activities (Fischer et al., 2019).

According to companies, it is also difficult to have access to universities. The (C4) company representative reports that access is restricted. The main contact the company has with those institutions is through the joint supervision of research theses or hiring of interns. "The company believes that much of the research carried out in universities has no practical application and that the private sector is distant from universities" (C4 company representative). The (C5) company representative also highlights the need to reduce the chasm between universities and society. The respondent points out that a large volume of knowledge produced by universities never reaches society. According to the interviewee, this knowledge should flow to society and generate economic value. For the respondent, the universities do not seek out society's needs, and those needs are often concealed because the public is not aware of the universities' potential to contribute to the solution of those problems.

Scarce Research Facilities and Resources

The existence of adequate facilities is a critical element in the research infrastructure of universities. Thus, access to spaces such as maker spaces and laboratories of institutions is highly valued by researchers and academic entrepreneurs. However, not all universities enjoy the privilege of having such spaces. In the case of Federal Institutes, for example, the scarce research infrastructure available is intended for teaching purposes rather than advanced research laboratories, which makes it difficult to set up innovation initiatives with firms.

Likewise, the lack of financial resources prevents the proper maintenance and supply of spaces for technological development. Therefore, this issue is yet another major challenge faced by TTOs. This problem is noticed even by organizations that partner with the institution. In an argument in favor of adequate laboratories for research, the (FI4) researcher argues that "if you have a cutting-edge laboratory for research, you can teach there. The opposite is not true" (FI4 researcher). In turn, these conditions hamper access to research grants, given the inadequate settings to build competitive R&D proposals.

Bureaucracy

At Brazilian universities, the excessive bureaucracy of control mechanisms makes it a challenge to set up collaborative agreements with companies, especially regarding intellectual property protection and technology licensing. The delay in the processes confirms the divergence of expectations between universities and companies (Bodas-Freitas et al., 2013). Companies report that the problem is the delay in getting answers concerning technology transfer processes (C1 company). In this sense, companies complain of the difficulty caused by bureaucracy and suggest that the solution would be to find an alternative that is not tied down by bureaucratic laws. Likewise, the literature reports bureaucracy as a barrier in the technology transfer process. Studies carried out at leading universities both in Brazil and abroad highlight this problem (Bodas-Freitas et al., 2013). In the same sense, the (C5) company representative shows how much bureaucracy can be harmful to the company.

> *. . .for the company this [bureaucracy] is very bad, because you have a schedule, an expectation, there is market demand, which at that moment you have to exploit, so to speak. When we have this type of gap in research, in support, we have delays in delivering projects and may even lose the timing of the innovation* (C5 company).

Even though public management, including with regard to agreements with private actors, requires processes that guarantee legality, morality, and impersonality, such routines cannot be overwhelmed by rules that hinder the smooth operation of work between partners, since in many cases the window of opportunity of companies for innovation is short.

Researchers

These limitations concern the excessive teaching workload of researchers, legal uncertainty in establishing ties with industrial partners, and the lack of ability to deal with the market. Another challenge found at Federal Institutes concerns their research culture. While regulations stipulate that applied research is a priority of Federal Institutes, many researchers insist on developing basic research, which rarely meets the demands of companies and moves these institutions away from their core objectives. In the perception of both researchers and TTO coordinators, it is very difficult for researchers to carry out applied research in line with local demands, as they have to learn the entire process or even change their line of research. In this sense, the culture of basic research learned at university is strongly present at Federal Institutes. It was noted that researchers such as those from (FI1) and (FI5) reported that their research is basic and does not generate immediate results that can serve the purpose of establishing innovation networks with industrial partners.

Intermediaries

The intermediary dimension features two main challenges that directly influence the flow of knowledge between universities and innovation ecosystems. The first concerns the understaffing of TTOs and the second relates to the protection of intellectual property and technology transfer.

Human Resources

Regarding human resources, staff numbers and turnover are the main critical elements. It is therefore understood that a well-prepared TTO team may significantly influence the results, since an experienced and market-oriented team are essential assets for TTOs to perform to their full potential (Schaeffer et al., 2021). At the investigated institutions, most TTOs operate with one or two employees and one or two interns. However, the employees are civil servants that were not hired specifically for the TTO; they are professors or technicians who are working there temporarily. In the case of TTO1, a single person is in charge of executing all activities, with the position of coordinator. According to this interviewee, he does not work full-time for the TTO. Understaffing discourages TTOs from taking on more complex projects. Sometimes it is even hard to follow through with routine activities. As stated by the TTO5 coordinator: "We need more human resources fast, urgently, to continue with the regular activities."

The interviewed researchers acknowledge this limitation, stating that the lack of staff at TTOs is a significant drawback. The (FI1) researcher stresses that the high turnover of fellows makes it hard to retain knowledge. The (FI2) researcher states that having a multidisciplinary team at TTOs would streamline the process, which could then be totally resolved internally without the need to resort to other departments of the institution. However, even better staffed TTOs, such as the TTO with two civil servants and three interns, believe internship positions should be occupied by regular staff, because "every time the interns leave, it's like starting from scratch again" (TTO2 former coordinator).

Regarding staff turnover, it was noted that this occurs with both TTO coordinators and interns, which makes it harder to manage knowledge efficiently. As there are few staff members, sometimes the person who leaves is the only one who possesses operational knowledge of the activities undertaken. "Some TTOs have only one employee, so if that person leaves, another arrives that knows nothing about intellectual property, which is a complicated subject" (TTO2 former coordinator). In this regard, researchers stressed the need for TTOs to have fixed employees to ensure the creation of memory and the retention of knowledge. They also highlighted the need for constant training.

These staffing problems at TTOs may be related to a broader structural issue of Brazilian public organizations, which lack flexibility to hire and manage human resources (Fischer et al., 2019). Providing TTOs with sufficient resources and qualified personnel is necessary for them to carry out their work effectively. This perception is in accordance with the early findings that technology transfer professionals should be the drivers of commercialization at research institutions (Bubela, Caulfield, 2010).

IP Protection and Technology Transfer

The TTO activities herein presented are in accordance with what Hayter et al. (2020) highlighted as activities of intellectual property protection, technology transfer, and support for entrepreneurship. Similarly, previous studies also found that the activities performed by Technology Transfer Offices focused on two main dimensions of technology transfer in universities: patenting and licensing (Clarysse et al., 2007; Siegel, Wright, 2015). The other activities aimed at supporting entrepreneurship and technological prospecting are not yet a reality at most TTOs, especially in Brazil (Schaeffer et al., 2021).

Although the main activity of the studied TTOs is the protection of intellectual property, some of them are still deficient in this respect, especially concerning patent registration. The TTO1 coordinator says no patent applications have been filed. In general, protection is done according to demand and covers several categories such as registration of trademarks, patents, software, or cultivars. Although this varies substantially from one institution to another, most registrations relate to software, trademarks, and patents. Despite the effort to protect intellectual property at the TTOs investigated and the positive results pointed out by some interviewees, the goal and assessment benchmark of universities should be technology transfer, since mere protection of intellectual property without transfer ends up creating a liability for the institution. However, as previously identified, research activities at the investigated institutions are mainly oriented toward basic science, rendering the intermediary role of TTOs limited in this respect. In addition, even the small numbers of intellectual property registered are not commercialized.

An Integrative Perspective on University-Industry Interactions in Peripheral Contexts

Over time, the generation and exchange of knowledge has become an important activity in all industrial sectors, no longer confined to complex R&D laboratories or the ivory towers which for many years housed academic research. Nonetheless, the various forms of knowledge production and exchange, despite being able to contribute to the advancement of knowledge, have considerable limitations. Laboratory research, for example, in striving for basic understanding, may overlook some of the complexities involved in industrial applications. These approaches have underscored several cases of successful relationships between different actors in innovation ecosystems that are considered mature or munificent. However, the literature has largely overlooked its impacts on emerging systems with low levels of absorptive capacity, low institutional density, scant innovation culture, and low economic density, where the main characteristic of the relationship between the actors is fragmentation. In this sense, the following proposition is put forward.

Proposition 1: Ecosystem conditions such as low economic dynamism, little capacity to absorb scientific knowledge, a lack of an innovative culture, and low institutional density moderate the benefits of university-business interaction in peripheral regions.

Different university-industry links can be identified in the context of local innovation networks. Research agreements, consultancy, and joint research are usually the relationships considered most important by several authors, along with patent licensing (Giannopoulou et al., 2010). In this respect, there is a concern about the possibility of attention shifting excessively to intellectual property rights at the expense of publishing research results – despite prior evidence indicating that patenting and publishing are complementary activities (Bourelos et al., 2017).

Notwithstanding the possibility of contributing in different ways to an innovation environment, universities embedded in peripheral regions face severe limitations regarding the availability of a research infrastructure that meets the needs of business partners. Companies developing research that requires more careful analysis have to set up partnerships with other institutions outside the region to solve industrial and societal problems. As far as research structure is concerned, the workload assigned to researchers often exceeds their ability to execute it regularly, which prevents them from engaging in new and sometimes more ambitious projects.

In addition, other organizational limitations such as excessive bureaucracy, the profile of managers and researchers and institutional culture may influence the decision to engage in innovation-driven linkages. It is also worth noting that not all universities and institution departments possess the characteristics required to contribute significantly to innovation networks (Kempton, 2019; Sánchez-Barrioluengo, Benneworth, 2019). Besides, other elements such as research fields and university size may be closely linked to the possibility of achieving greater or lesser success in relationships. Given the above, the following proposition is presented.

Proposition 2: The organizational conditions of universities, such as the lack of adequate facilities, resources, excessive bureaucracy, work overload for researchers, and the difficulty in joining business networks hinder the interaction of these institutions with the productive sector in peripheral regions.

In the past few decades, the number of intermediary organizations playing a brokering role in innovation ecosystems has increased significantly. In this article, focus has been given to universities' TTOs, which work mainly in protecting intellectual property, supporting innovative entrepreneurship, and interacting with companies. The studied TTOs face severe limitations that constrain their ability to effectively promote further integration between universities and the broader ecosystem. Although some of these limitations are attached to the internal organizational structure of the university, some challenges associated with regulatory frameworks that apply to public entities are also present – thus going beyond the institutional control of individual universities. Excessive bureaucracy, for example, is not only an internal limitation at TTOs, but also affects most universities and public bodies (Bodas-Freitas et al., 2013). Another limitation concerns the staff size assigned to these bodies, as well as their training. Research by Stankevičienė et al. (2017) found a positive relationship between the efficiency of technology transfer offices and the number of qualified staff, motivation systems, and good relationship between TTOs and researchers.

In addition to the above, contextual features directly influence the activities of TTOs, since the regional innovation culture is likely to affect how the academic community perceives technological activity as part of its mission. Thus, it is more difficult to implement an innovation culture at a university in a context in which such a culture is absent. Other aspects such as the lack of interest in interacting with universities, the lack of knowledge or distrust directly interfere in the performance of TTOs. Therefore, the following proposition is presented.

Proposition 3: The results of TTOs linked to universities in peripheral contexts are negatively affected by the lack of staff, high staff turnover, and the lack of technological prospecting and scarce technology transfer activities. This reveals the fragility of TTOs in supporting university-industry interactions in these regions.

The propositions presented summarize some limitations inherent to university-industry ties in a peripheral context, especially when the focus resides on innovative endeavors.

Concluding Remarks

Our assessment focused on university-industry interactions in a three-dimensional approach, analyzing ecosystems, universities, and TTOs, which act as an interface between universities and the productive environment. It was found that all three dimensions contain elements that constrain knowledge flows between academic and business partners, and these are mostly attached to level of maturity in innovation ecosystems located in peripheral contexts.

Our findings indicated that the entrepreneurial university concept requires a careful reexamination when dealing with academic institutions embedded in such regions. Initiatives ranging from structural public policies to managerial decision-making at the organization or department levels to ensure an improved flow of knowledge and technology are required. However, the solution is not simple, as some issues lie outside the competence of universities or TTOs. Further involvement of multitudinous local-level stakeholders is necessary so that, in the long run, the ecosystem may become more conducive to the establishment of successful innovation networks. Unfortunately, attempts to develop regions by establishing or promoting universities are often characterized by short-termism. In this regard, our research contributes to the literature by addressing in detail the limitations of universities in spurring dense innovation networks in laggard ecosystems. Instead, more complex co-evolutionary processes seem to be at play – and "silver bullet" policies are likely to offer disappointing results. The heterogeneity between different academic institutions highlights the impossibility of adopting a one-size-fits-all model in terms of education, research, and technology transfer activities (Baglieri et al., 2018; Kempton, 2019).

Our set of propositions highlights key moderators and barriers in this realm, offering academics and policymakers a roadmap to guide the support of entrepreneurial universities when embedded in peripheral ecosystems. Corresponding implications involve a broader comprehension of innovation networks involving universities – rather than simply setting up TTOs. Nevertheless, our assessment does not go without limitations. Our inductive exercise has drawn qualitative information from the specific context of the State of Minas Gerais, Brazil. Thus, further assessments on this topic should address context-specific elements. Deductive assessments based on quantitative data are also due in order to provide academic and policymakers with a clearer perspective on the limits of the entrepreneurial university discourse.

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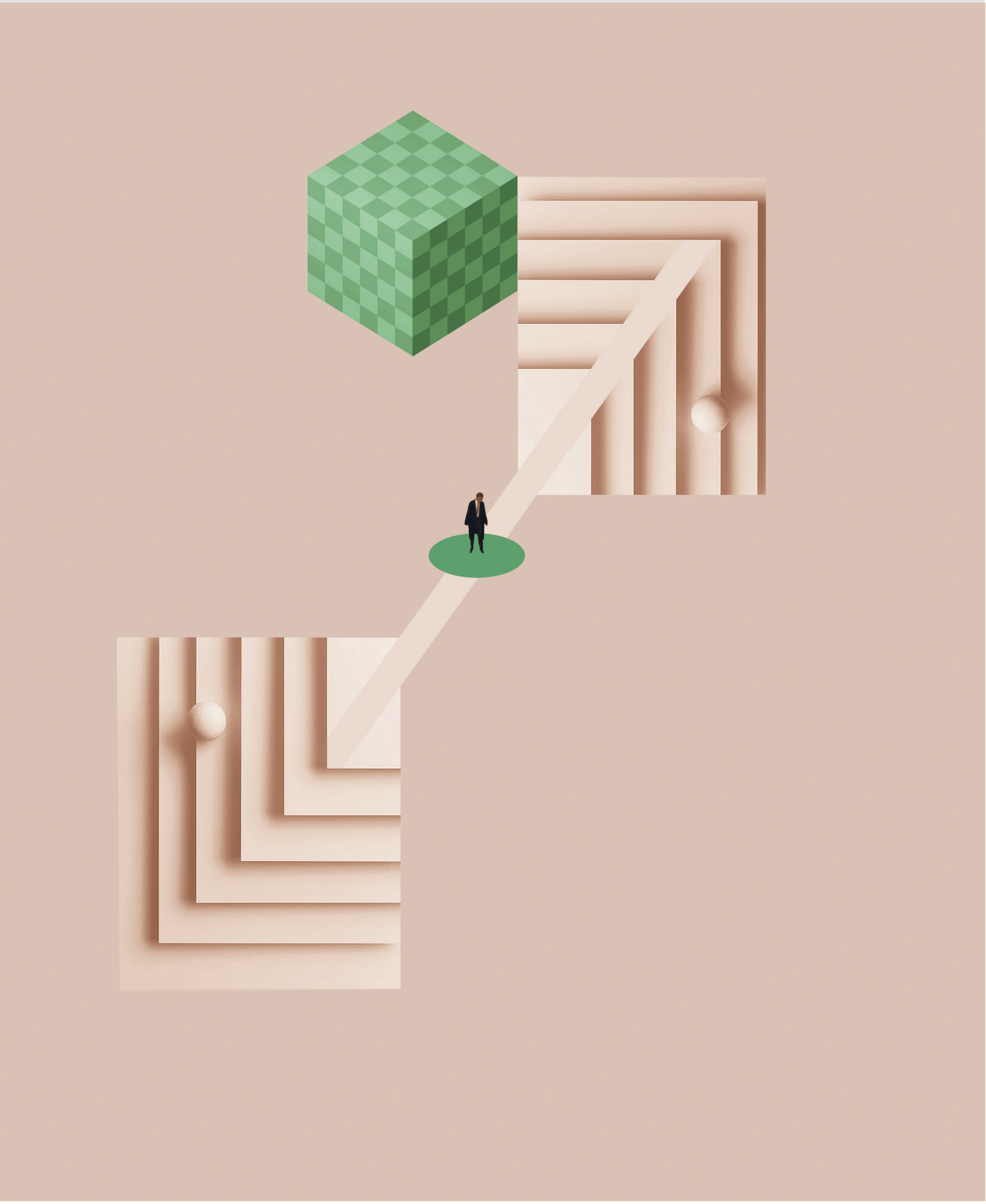

Maturity Assessment of Critical Technologies

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Abstract

A maturity assessment of technological projects is becoming an increasingly popular tool for innovation policy. It enables the accurate determining of risks and opportunities related to the creation of high-tech products. Determining the degree of technology readiness, especially at early stages of development, increases the performance of not only government programs, but also of business projects. This article presents a software interface for such expertise, the IAE/ITA TRL Calculator, designed for the Brazilian aerospace sector. The validation within a number of cases revealed its potential applicability in a wide variety of industries. This innovative software product includes a quality user guide and an improved visual interface that allows for easy and quick identification of issues that require additional effort in order to move the evaluated technology project to a higher level of readiness.

Keywords: innovation; TRL; technology readiness levels; maturity; project management; decision support; TRL Calculator; analysis; evaluation; risk; innovation policy

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Introduction

Innovation is the basis for economic development (Schumpeter, 1934) and for the competitiveness of companies (Porter, 1999). The incentive to innovate in Brazil was tangible more emphatically after 1950 with the creation of CAPES.[1] Although the incentive to foster technological innovation in Brazil began in the 1950s, the country was left out of the space race.

When previously the competition was for nations to reach space, currently this race occurs between different players - private companies. This relevance is confirmed by the high investments from both the government and private sector in search of financial return and positioning of sovereignty and technological independence that the sector provides.

Bryce Space and Technology, which analyzes the space sector, reported that the aerospace industry is currently valued at $360 billion. Bank of America, Space Capital, and Silicon Valley reported that the industry will turn over $1 trillion in the next decade in their prospecting studies.[2]

Although Brazil is not one of the leading countries in the competition, it is the holder of cutting-edge technologies, and is improving our innovation indicators, see Figure 1 (Cornell University et al., 2021).

An example of Brazil's progress in innovation and cutting-edge technology was the launching of Amazônia-1, the first Earth observation satellite entirely designed, integrated, tested, and operated by Brazil. Its launch took place on the PSLV-C51 mission of the Indian Space Research Organisation (ISRO) on February 28, 2022.[3]

The mission represented a technological breakthrough and improved development in innovation. In confirmation of the improvement in Brazil's innovative development, a survey conducted over the last five years (2015-2020) on the innovation indicators of the Global Innovation Index[4] (Figure 1), Brazil has been improving its positions, both in the global index, as well as in the indicators of input to innovation (input) and products of innovation (output).

Analyzing the data in Figure 1 we observe that Brazil has been improving its Global Index over the last five years (2015-2020), moving from 70th place to the 62nd, improving eight positions in the overall ranking. This improvement was mainly in the year 2017-2018 and influenced by the improvement of 10 points in the ranking in Innovation Products and two points in Innovation Inputs.

In 2018, research and development (R&D) spending grew by 5.2%, which is significantly more rapid growth than overall GDP growth. That same year Brazil held 10th place among countries with the most global downloads of apps produced by local companies (Cornell University et al., 2018).

Brazil followed in 2019 and 2020 with its improvements in innovation. As shown in Table 1 - Brazil's position in the ranking of the General Innovation Index in the Global Innovation Index by subdivision (2015-2020), the positioning score goes from the worst of the last five years as red following to yellow as medium, and the best score with green.

Brazil obtained not only its best placement in the Global Innovation Index ranking for the last five years (2015-2020) in 2020 but also its best positions in the subdivisions of business sophistication, recognition products, and technology and creative outputs, it also obtained relevance in the subdivisions of human capital and research, in which the University of São Paulo (USP) obtained 5th place in recognition among the 10 best ranked universities in middle- or low-income economies[5].

One factor pulling Brazil's scores upwards are technology companies, universities, and laboratories focused on the aerospace sector. Within the aerospace sector, the technologies are considered complex, so the need for technological development is high performance (OECD, 2005). These are the technologies considered: "Critical Technologies (CT)" because they are often military applications and within the scope of a country's defense (Salgado, 2016; Rycroft, Kash, 2002).

In the 1990s, the United States of America (US) government defined Critical Technology: "a technology is considered critical when it is essential for the US to develop its long-term national security and the country's economic prosperity."[6]

For the Brazilian Institute of Aeronautics and Space (IAE), TCs are: "Technologies necessary for development not dependent on the projects and programs established by the Institute." The term "non-dependent" in this context refers to a partial mastery of space technologies, full independence is possible only for the great powers in this area, which have complete space programs (Salgado, 2016)

The development of TCs is a *sine qua non* condition for access to space, providing the countries that have them: "sovereignty and autonomy", in addition to economic factors. They grow an average of 6% per year and yield billions of dollars (Salgado, 2016). Access to space requires highly complex technological development and more complete management, due to the high risk.

In order to reduce the risk, in the 1960s, the National Aeronautics and Space Administration (NASA), the US national aeronautics and space administration agency, developed a metric to assess the level of technological maturity in the development of its technologies, called: Technology Readiness Level, known by its acronym TRL.

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1 Followed by FNDCT, BNDES, and FINEP, created to encourage and finance the propulsion of innovation in Brazil.

2 https://www.cnbc.com/2022/05/21/space-industry-is-on-its-way-to-1-trillion-in-revenue-by-2040-citi.html, accessed 17.06.2022.

3 https://www.isro.gov.in/launcher/pslv-c51-amazonia-1, accessed 19.06.2022.

4 The Global Innovation Index evaluates as indicators of innovation: venture capital, research and development, entrepreneurship, and high-tech production.

5 https://www.topuniversities.com/university-rankings-articles/latin-american-university-rankings/top-10-universities-latin-america-2020, accessed 15.06.2022

6 https://clintonwhitehouse3.archives.gov/WH/EOP/OSTP/CTIformatted/AppA/appa.html, accessed 12.03.2022.

The main goal of such a development was to reduce the risk of technology transition from its creation to its use, as shown in Figure 2 (NASA, 2020). Thus, the Technology Readiness Level metric, henceforth TRL, also made it possible to compare different types of technology and their common understanding. The metric consists of measuring the maturity of technology by demonstrating technological capability and being highly effective in communicating the state of technology (Mankins, 2009).

The TRL metric currently consists of nine levels that evaluate technology (Mankins, 2009), the levels range from basic research to experimental development to technology, i.e. considered an R&D (research and development) metric.

The GAO (US Government Accounting Office (USA)) uses the TRL metric to define projects to be developed and does not use technologies with TRL less than 6 in its projects. The European Commission in its Horizon Europe research program has also used the metric in defining investment estimates in selected projects.[7] In Brazil, Embrapii, in a government action to promote innovation, used the minimum cut-off for TRL of 3 for its projects.[8]

There are numerous adaptations today regarding the application of the TRL metric. In the US we have four institutions that use the metric in different forms: the calculator developed by the US Air Force Research Laboratory[9], called the TRL Calculator; which is already in its second version; the guidance developed by the Department of Defense (DoD, United States Department of Defense)[10]; the NASA checklist and the GAO checklist.[11] The European Space Agency (ESA) has a Handbook exemplifying their way of applying the metrics (ESA, 2008). In short, the application process has been adapted and specified according to the characteristics of each institution.

In Brazil, funding institutions and research institutes[12] use the TRL metric as a prerequisite for project submission and project controls to define the current status of the project and the set goal.

In Brazil, in addition to the natural challenge of space technologies due to high risks and lack of technical knowledge, the biggest challenges to develop space activity are two: human and financial resources.[13] Thus, Brazil aims to differentiate itself from the world's great aerospace leaders. Given the reality of the Brazilian aerospace context, there was a need to adapt the TRL metric to the country's reality.

Technology Readiness Level

The TRL metric was developed by NASA in the 1960s. Initially, there were seven levels that differentiated and defined technological maturity, in the 1990s the metric was revised and it was found that two more levels were needed bring the total to the current nine levels of technological maturity. In the same decade, a definition of each of these levels was published (Mankins, 2009).

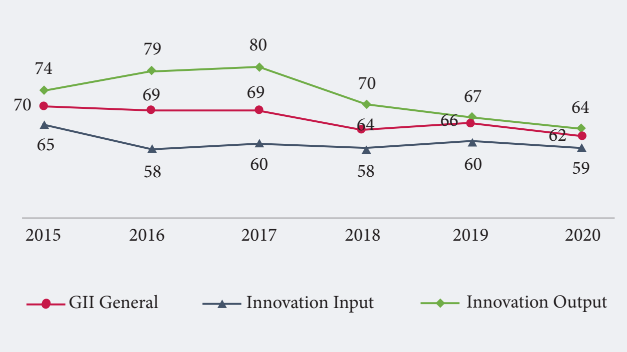
Due to the popularity of the metric and the superficial definition of each level, a large number of institutions and sectors have pivoted and adapted the TRL metric. The popularity and validation of the metric's relevance was confirmed with a bibliometric analysis that allowed for identifying the growing number of publications using the metric in technological projects (Araujo, 2020).

The bibliometric analysis took place on the Web of Science platform database, "Technology Readiness Level" OR "Technology Readiness Levels" in the technology domain: "Main Collection"; the survey was based on a timeline from 1991 to 2021 (as shown in Figure 2). The cutoff at the beginning of the analysis in the 1990s was due to the decade of the first publication explaining the then nine levels of technology maturity.

There were 1,103 published papers that used TRL, conducted by 71 different countries, the most relevant being the US with 39% of all publications, followed by England and Germany with 12% and 11%, respectively. The publications were identified in 124 different categories, with 53% of the publications in the engineering field and 19% of them with specific application in aerospace engineering.

As shown in Figure 3, there is a spread of metrics and an increase in the number of publications in the 2010s due to the ISO Standard that was released in 2013. ISO 16: 290: 2013 Space Systems - Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment (later translated by ABNT NBR ISO 16: 290: 2015 Space systems - Defini-

Figure 1. **Position of Brazil in the Global Innovation Index ranking (2015-2020)**



Source: authors, using GII data.

[7] https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf, accessed 19.02.2022.

[8] https://embrapii.org.br/wp-content/images/2020/08/MINUTA-RELATO%CC%81RIO-ANUAL-2019-EMBRAPII-Vers%C3%A3o-Final-SAF-L1_revisado.pdf, accessed 07.03.2022.

[9] http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104463/air-force-research-laboratory.aspx, accessed 06.06.2022.

[10] https://www.researchgate.net/file.PostFileLoader.html?id=5566cff45cd9e318e88b4696&assetKey=AS:273785192681472@1442286884102, accessed 11.01.2022

[11] https://www.gao.gov/assets/gao-20-48g.pdf, accessed 04.01.2022.

[12] Such as Embrapa, INPE, UFAN, PROFNIT, as well as AEB-Brazilian Space Agency.

[13] https://www.gov.br/aeb/pt-br/centrais-de-conteudo/publicacoes/institucional/PNAEPortugues.pdf, accessed 06.06.2022.

Table 1. **Position of Brazil in the ranking of the General Innovation Index in the Global Innovation Index by subdivision (2015-2020)**

Subdivisions	Years					
	2015	2016	2017	2018	2019	2020
General Ranking	70	69	69	64	66	62
Institutions	85	78	91	82	80	82
Human Capital and Research	63	60	50	52	48	49
Infrastructure	67	59	57	64	64	61
Market Sophistication	87	57	74	82	84	91
Business Sophistication	37	39	43	38	40	35
Knowledge and Technology Outputs	72	67	85	64	58	56
Creative Outputs	82	90	83	78	82	77

Source: Authors. Data collected from the Global Innovation Index (2015-2020).

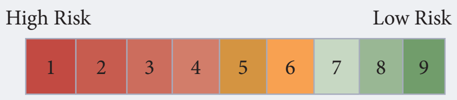
tion of Technology Maturity Levels (TRLs) and their assessment criteria): "This Standard defines Technology Maturity Levels (TRLs). It is primarily applicable to materials related to space systems, although the definitions can in many cases be used in a wider domain."[14]

By performing the Forecast (Figure 4), one can identify an even more impressive growth in the number of publications and implementations in the following years.

The Standard was created to focus on the aerospace sector and focused primarily on software, as described therein. Olechowski et al. (2015) detects some of the most aggravating flaws found in ISO 16290: 2013, however, the benefits of the metrics are greater (Dawson, 2007) (Table 2). The TRL metric assists in the management of technology projects. Its relevance is indicated by the NAP, which stresses the importance of industrial advancement in the space sector (Salgado, 2016).

GAO published a study on their projects using only technologies with a TRL above TRL 6 against projects with any levels of TRL for the technologies (Sullivan, 2007). The result was that in projects with a TRL above TRL 6, there was no schedule delay and no budget growth forecast, while in projects using a TRL below TRL 6, there was up to a 120% schedule delay and a 101% budget growth.

Figure 2. **Level of risk for technology transition**



Source: authors, using (NASA, 2020).

Its relevance is also proven by the aerospace institutions that have been using and adapting the standard to the reality they are experiencing. Among them are those mentioned above: NASA, ESA, AFRL, and DOD, as well as JAXA (Japan Aerospace Exploration Agency), MCTI (Ministry of Science, Technology and Innovation), INPE (National Institute for Space Research), and the Brazilian Armed ForcesIn addition there are private sector companies that employ this standard such as: ALSTON, Google, Embraer, Raytheon, and others (Rocha, 2016).

Materials and Methods

The authors want to mitigate the shortcomings of applying the metric using only the parameters of ISO 16290: 2013 and are motivated by the intention to make the application of the TRL metric feasible and easy. The stipulated parameters were not only addressed by NBR ISO 16290: 2015 but also by added views on economic, political-legal, technical, and knowledge management feasibility.

The first version of the calculator was based on applications from the following institutions: NASA, ESA, DOD, and AFRL, as well as the checklist described in ISO 16290: 2013. After its development, the TRL calculator received recognition for its importance and ease of use by some Brazilian institutes for development[15] and it has more than 20 applications made by IAE researchers.[16]

Along with the recognition and popularity of the TRL Calculator, opportunities for improvement were identified. Among them:

- Differentiation in the weights of the analyzed areas.
- Bias in questions marked as ISO.
- Lack of clarity regarding the improvement with only the visualization of the result in the dashboard.
- Doubts in the understanding of some questions.
- Difficulty in applying it to technologies outside the aerospace sector.

Aerospace institutions already apply TRL and have publications with some differences in the application of the metric (Rocha, 2016). The differences were analyzed for the construction of the first version of the Calculator and maintained for the current version, with an update only in the fifth part of the TRL application process. The five analyzed application parameters are presented at Table 3.

The IAE/ITA TRL Calculator

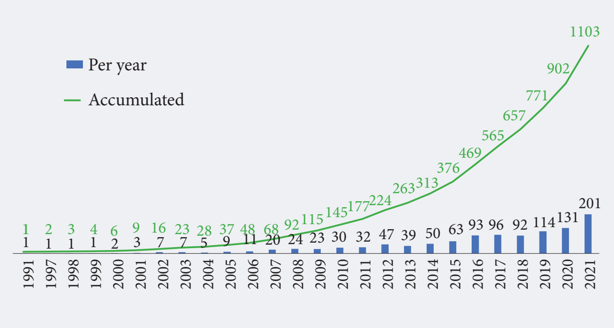
The IAE/ITA TRL Calculator is a tool that assists with the assessment of TRL that is now in its second version. The calculator assists in the fifth step of the assessment process.

[14] https://www.target.com.br/produtos/normas-tecnicas/43781/nbriso16290-sistemas-espaciais-definicao-dos-niveis-de-maturidade-da-tecnologia-trl-e-de-seus-criterios-de-avaliacao, accessed 06.06.2022.

[15] Among them are ABDI - Brazilian Agency of Industrial Development , IAE- Institute of Aeronautics and Space, Brazilian Space Agency, PROFNIT.

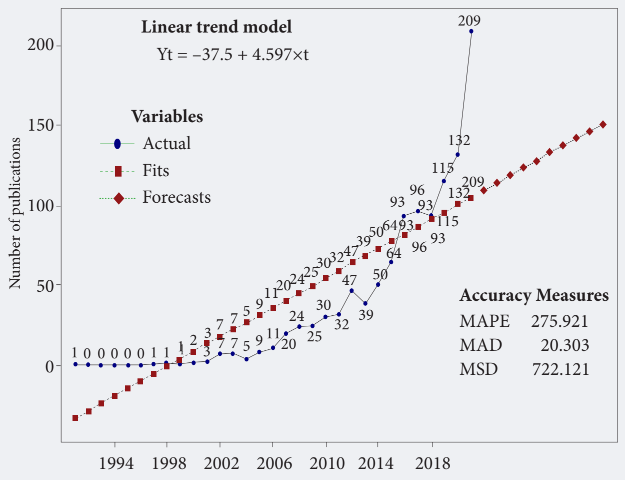
[16] https://iae.dcta.mil.br/index.php/calculadoras-trl-e-mrl, accessed 06.06.2022.

Figure 3. **Dynamics of growth for TRL-related publications, by year of publication**



Source: authors, using (Salgado, 2016).

Figure 4. **Forecasts for growths of TRL-related publication flows**



Source: authors.

The TRL metrics are included in the tool provided in Microsoft Excel software. During the evaluation stage, technical, economic, political-legal, and documentary aspects were included in addition to the framework issues of NBR ISO 16290: 2015.

The demonstration of the TRL evaluation methodology consists of standardizing knowledge about the TRL methodology, using the Calculator created in Microsoft Excel software with the TRL concept used for standardization:

"TRL is a demonstration tool that assesses the maturity of a technology, product or project. It helps decision makers to get an accurate result. Helps keep projects within a predetermined cost, time and effort. Provides stakeholders with a common understanding of managers, technicians and researchers. Defines the status of the technology, facilitating feedbacks, technology comparisons, and future decision making."[17]

The process of applying the TRL assessment using the Calculator occurs in four steps, they are:

1. The methodology demonstration process is the process in which the facilitator seeks to standardize the knowledge of the TRL indices for the assessment respondents, placing everyone with a minimum knowledge of the levels and the prerequisites for the levels, as well as explaining the assessment concept and its benefits.
2. Technology data consists in identifying and framing the technology to be evaluated.
3. The technology weights consist of the consideration of the weights per criterion to be evaluated.
4. The maturity evaluation consists of a questionnaire to be answered and a checklist to be performed of the materials collected.

The first step, for demonstration purposes, has as an aid the first part of the Calculator that has access to the basic criteria of the NBR ISO Standard and a Manual that explains how to use this tool, and the start button that takes the responder to the second step (Figure 5).

The content of the Handbook (Figure 6) consists of an explanation of the background of the TRL, followed by an explanation of the use of the application in Microsoft Excel, as well as an explanation of the calculations performed to obtain the result. Furthermore, it includes an explanation of how to read the result obtained with the Calculator.

We also have checklist criteria withdrawn from the ABNT NBR ISO 16290:2015 Standard (Figure 6). It contains three columns: 1. The definition of each level of technological maturity, 2. The framework achieved for each level or what needs to be done for the completion of each level, and 3. The necessary documentation for each level.

Clicking the start button shown in Figure 5 will open the second step (Figure 7) that consists of answering questions

Table 2. **Benefits and Flaws of TRL metrics**

Flaws (Olechowski et al., 2015)	Benefits (Dawson, 2007)
• It does not evaluate know-how, only documentary data; • It does not evaluate the means of knowledge transfer; • Does not address political legal aspects; • It does not standardize the evaluation; • Does not address economic and documentary aspects; • It does not perform quantitative analysis.	• Ease of common understanding about the current state of technology for a given application; • Comparison of technologies in their current phases (snapshot); • Risk management; • Decision making related to technology financing; • Decision making related to technology transition; • Metric assessment of the maturity of the project›s technologies program, before development begins.
Source: authors, based on the abovementioned works.	

[17] https://iae.dcta.mil.br/images/Calculadora_MRL_e_TRL/CalculadoraTRLIAEITA2020.xlsm, accessed 12.06.2022 (in Portuguese).

Table 3. **Analyzed application parameters**

Parameter	Description
1. Application Decision	It must be carried out via the evaluation process call, and can take two forms: pre-established frequency, or only when something changes in the project or technology, according to GUIDANCE, ESA
2. Term Definition	Presence of the facilitator, person responsible for the application of the metrics and conference (documentary audit) (FERENCE, 2012), in addition to the researcher, knowledgeable of the evaluated technology, the manager responsible for the development mission and the knowledgeable of the operational environment (NBR ISO 16290, 2013).
3. Identification of technologies	The evaluation must be carried out on all technologies, complete model; in the case of up grade only associated technologies (NASA, 2007).
4. Collecting materials	The assessment must be carried out by means of a documentary checklist, as described in NBR ISO 16290: 2015. The audit process must be carried out together with the technology development team.
5. Evaluation	The TRL assessment takes place in 3 steps: a) demonstration of the TRL assessment methodology (consists of standardizing the knowledge of what is TRL for all respondents to the assessment); b) data of the technology to be evaluated (identification and framework of the technology to be assessed - the framework may be research and development; construction of the technology and validation and production); c) TRL evaluation (questionnaire to be answered and checklist performed to complete the achieved TRL).

Source: authors.

about the technology data. All answers in this part consist of collecting data for documentation purposes, i.e., they have no influence upon the maturity assessment calculations.

These are the name of the technology, the current respondent, and the date of the assessment. It is necessary to digitalize these fields. The other questions to be answered consist only in selecting in which field the evaluated technology fits, these prompts include the type of technology and the application of the technology.

The type of technology to be evaluated is the definition of whether a technology is hardware or software. The intended status consists of saying which status you want the technology to reach and there are three statuses: research and development, technology construction, and validation and production, which are explained in Table 4. Further the technology application can be classified as infrastructure, distribution, or application. Infrastructure technologies are technologies considered disruptive or basic. They are the bases of technological development, the technologies that will be allocated to a vehicle or satellite. Distribution technologies are the technologies that allow the application technologies to exist, they are middle technologies. Finally application technologies are the technologies that go to the final consumer.

Clicking the START EVALUATION button will open the third stage of the Technology Data evaluation, the stage where you will indicate the weights for each of the aspects included in the evaluation, Figure 8.

As weights, there is the possibility of including five levels for each of the criteria, according to the Likert scale, which is a scale for questionnaires, widely used for questions with a higher level of nuances than a yes or no answer and is great for delving into a specific theme and finding out more detail. The weights were stipulated by the degree of importance with the respondent being able to place maximum importance on all of them or none of them.

There are five criteria, which are evaluated: the NBR ISO 16290:2015 Standard; the technical knowledge criterion of technology development; the economic criterion of feasibility and the economic potential of the technology; the political-legal criterion of feasibility and potential for technological development and technological commercialization; and lastly the documentary criterion of the security of knowledge management for the developed technology. The weights are defined through a Likert scale, which defines five levels of importance: 1 - Not important; 2 - Not very important; 3 - Moderately important; 4 - Important and 5 - Very important. The weights impact TRL calculations.

After choosing the weights that best fit the technological development profile, the respondent must mark the degree of tolerance accepted for level compliance. It is worth mentioning that the AFRL uses an 85% level for the fulfillment of development as approval to move on to the analysis of the next level, accepting a 15% tolerance of non-compliance with the requirements.[18] The AFRL seeks to develop technologies up to TRL 6, then transfer the activities to the development sector. The degree of tolerance will be stipulated by the respondent.

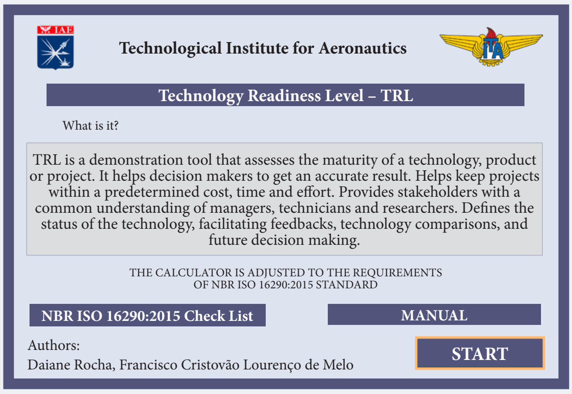
The tolerance calculation is based on the groups, all respondent questions of TRL 1 add up to 100%. If the tolerance is 85%, the respondent may not meet 100% of any of the questions, within the 85% threshold, if non-compliance is greater than the tolerance, it will result in the TRL value.

After setting the tolerance level, the respondent clicks the START ASSESSMENT button , and will be transferred to the questions page (Figure 9).

This screen contains the name of the evaluated technology, the name of the respondent, and the evaluation date. The questionnaire is divided by nine TRL level blocks and these blocks contain questions that fall under the five criteria (NBR ISO 16290:2015, technical, economic, political-legal, and documentary), however the respondent will not have visibility. There are questions that fit more than one criterion and will be counted for both criteria (Table 7). The respondent can select how much they have already fulfilled the question in the prompt, with the answer ranging from 0

[18] https://apps.dtic.mil/sti/pdfs/ADA411872.pdf, accessed 07.02.2022.

Figure 5. **IAE-ITA-2021-1 Maturity Calculator Home Page**



Source: https://iae.dcta.mil.br/images/Calculadora_MRL_e_TRL/CalculadoraTRLIAEITA2020.xlsm, accessed 12.06.2022 (in Portuguese).

Table 4. **Technology Status**

TRL Level	TRL Group	TRL Group Description
1–3	Research and Development (R & D)	Research and technology exploration activities, discovery and formulation of the technology concept to be developed.
4–6	Technology Construction	Development of the technology and application concept (prototype), experimental testing of the technology carried out in a relevant laboratory environment.
7–9	Validation and Production	Demonstration in aerospace, qualified system and mission achieved, possibility of scale reproduction, partnership process and technology transfer to industry.

Source: authors, using (NASA, 2020).

to 100 in multiples of 5 (to change the value, simply select the arrows on the drop down menu of values present at the beginning of each question).

After filling in the complete questionnaire (113 questions), a comparison of the results is possible. The comparison can only be made with questions from NBR ISO 16290: 2015 and the total score for the questions is developed by added criteria. The result is a dashboard that aims to handle the questionnaire data and explain in a clear and intuitive way the gap in the development of the technology for advancement to the next level through the radar graph (Figure 10).

To construct the radar, the Delta TRL was used. In 2002, Mankins presented the definition of the Delta TRL as the difference between the current level of maturity of a given technology and the desired level of TRL for a given point in future time (Δ TRL = TRL Desired - TRL Actual). This is because, each stage represents another level of maturity in the development, therefore, more stages would typically be equivalent to the highest level of uncertainty in R&D over a given period of time (Mankins, 2002).

The importance of this analysis lies in the relationship between the increased level of TRL and the increased costs of technological development projects. Two factors that have a direct influence upon the development schedule (Araujo, 2020).

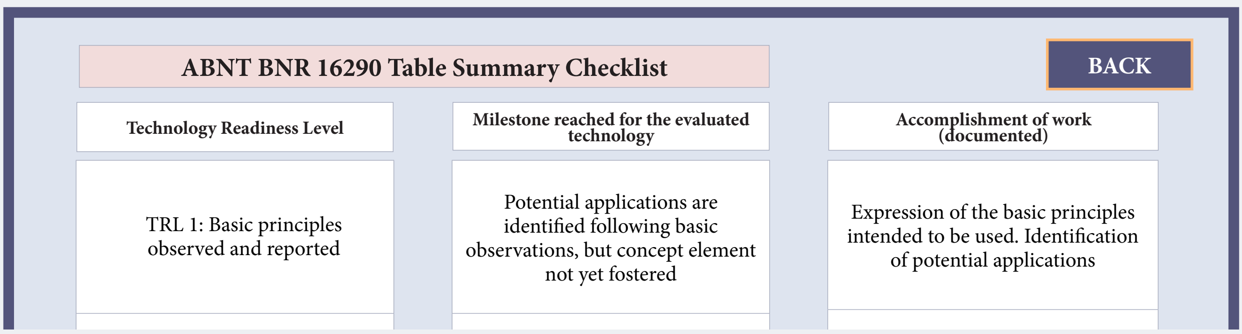
The application for the validation of the developed methodology took place in four technologies of the aerospace sector. The technologies were chosen to comparatively analyze the following aspects:

- Application in different sectors: one defense technology, MARIMBA, and three space technologies: Carbon Fiber-Reinforced Thermoplastic Composites, L75 Engine, and VSB 30.
- The completed projects (MARIMBA and VSB 30) and ongoing projects (carbon fiber reinforced thermo-structural composites and L75 engine); and
- Technologies with a systemic view (VSB 30, L75 Engine, and MARIMBA) and basic technology (carbon fiber reinforced thermo-structural composites).

Table 5 provides a brief description of the technologies that were evaluated:

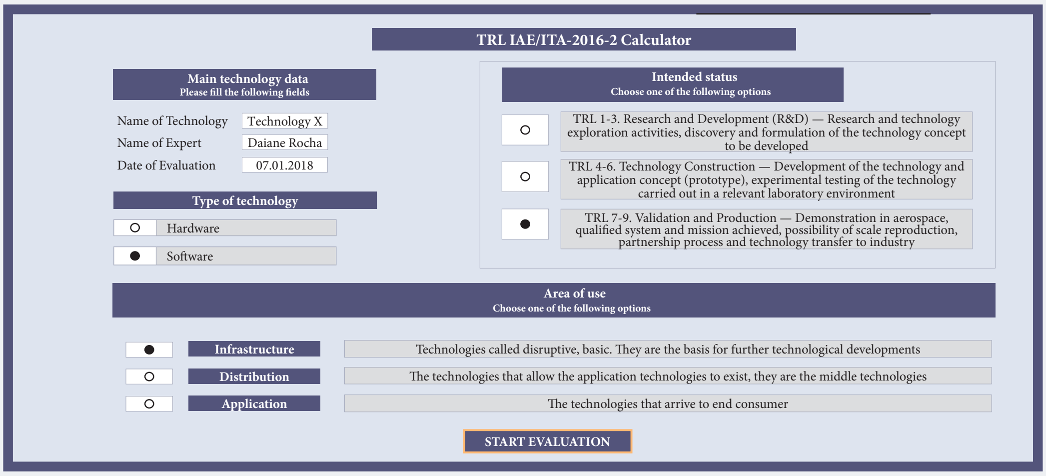
The evaluation process took place through interviews with experts lasting approximately two hours. The application of the methodology followed the five steps mentioned above. The application was done using the second version of the

Figure 6. **Query the requirements of the standard (Adapted from NBR ISO 16290, 2015)**



Source: https://iae.dcta.mil.br/images/Calculadora_MRL_e_TRL/CalculadoraTRLIAEITA2020.xlsm, accessed 12.06.2022 (in Portuguese).

Figure 7. **Technology Data**



Source: https://iae.dcta.mil.br/images/Calculadora_MRL_e_TRL/CalculadoraTRLIAEITA2020.xlsm, accessed 12.06.2022 (in Portuguese).

TRL IAE/ITA Calculator tool for the evaluation. The weights were all set to the same value.

Results

In three of the four evaluations performed, the NBR ISO 16290: 2015 Standard obtained a more advanced TRL than the TRL with requirements created for the Calculator. In addition, the VSB 30 technology obtained the maximum TRL in both evaluations.

Besides the VSB 30 technology, which proved to be neutral in representing the subjectivity of the NBR ISO 16290: 2015 Standard, the other evaluated technologies confirmed the raised aspects of modifications of the first version and demonstrated the subjectivity in 75% of the evaluations.

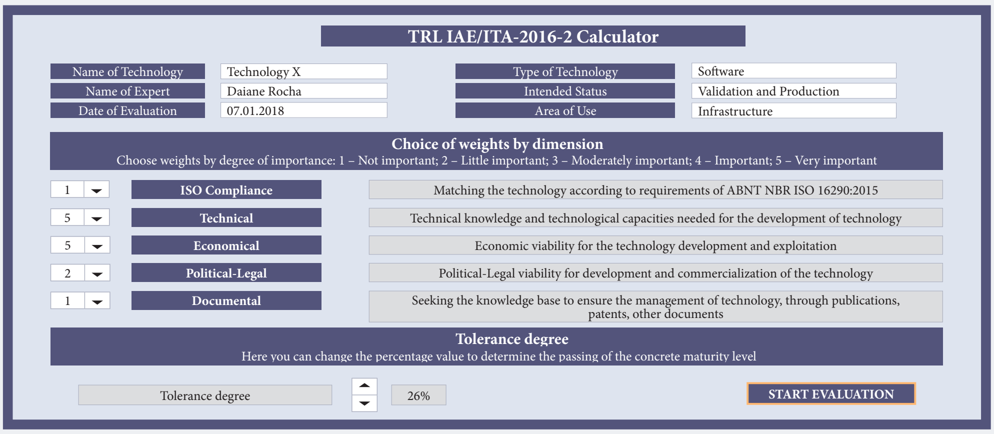
The relevance of including the added aspects was confirmed by the interviewed researchers and managers. The documentary concern mitigates knowledge transfer, since all steps and know-how for technological development are documented. The transfer to industry added in the last TRL proved to be relevant for possible production at scale, the inclusion of economic issues, and the development of a business plan makes this transfer feasible.

The inclusion of political and legal aspects for embargo issues proved relevant for enabling development. The use of quantitative and qualitative data allows the manager to make a detailed assessment of the aspects of project development and makes strategic decision making possible. The evaluation process developed a standardization of the evaluation, helping in a comparison of similar technologies and technologies in different projects, apart from the comparison between projects.

The dashboard visualization of the results proved useful for the interviewees and the data was easy to understand, showing the points that need to be improved to obtain the next maturity level.

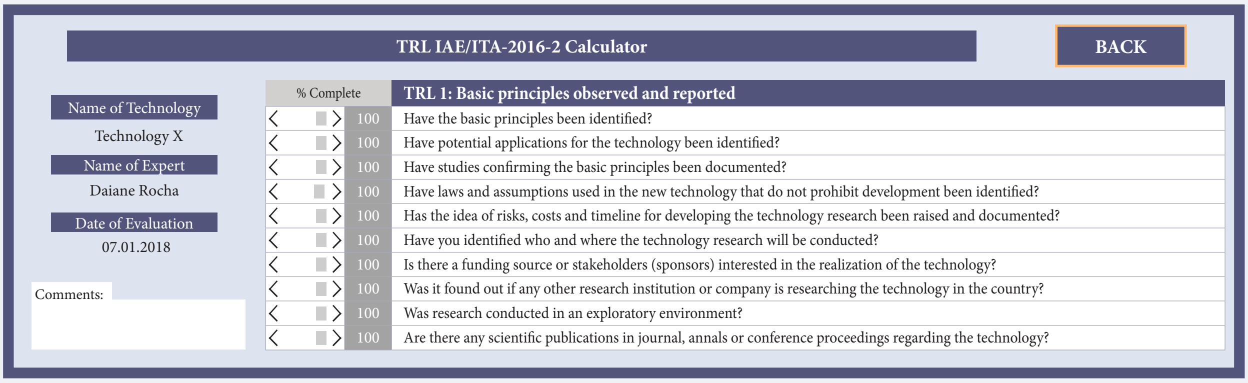
In order to validate the application of the metric used in the IAE/ITA TRL Calculator tool and the inclusion of Delta TRL, the present work used four projects in the area of propulsion

Figure 8. **Technology Weights**



Source: https://iae.dcta.mil.br/images/Calculadora_MRL_e_TRL/CalculadoraTRLIAEITA2020.xlsm, accessed 12.06.2022 (in Portuguese).

Figure 9. **Technology Maturity Evaluation**



Source: https://iae.dcta.mil.br/images/Calculadora_MRL_e_TRL/CalculadoraTRLIAEITA2020.xlsm, accessed 12.06.2022 (in Portuguese).

that had already been evaluated by Salgado (2016). These technologies were identified by the IAE as technologies considered critical and the institute aims for their development (Salgado, 2016). Aiming at the comparison of results. These projects were: C/C Canyon Tubing (Garganta de Tubeira C/C), Turbopump (Turbobomba), Combustion Chamber (Câmara de Combustão), and the Liquid Propulsive Stage (Estágio Propulsivo Líquido).

The construction of a roadmap by Salgado (2016) was conducted through workshops, involving opinion polls, with researchers from the areas involved in 2014. Thus, a methodology was not used to guide the maturity analysis (TRL) of the technologies under development. For this reason, four projects were selected for the application of the TRL metric through the Rocha, 2016 methodology and of the second version of the IAE / ITA TRL Calculator, which considers national and specific criteria for the aerospace sector and the ABNT NBR ISO 16290: 2015 standard.

Below, in Table 6, are presented the results of the TRL analysis of the four projects in the propulsion area, which were compared with the data obtained by Salgado (2016).

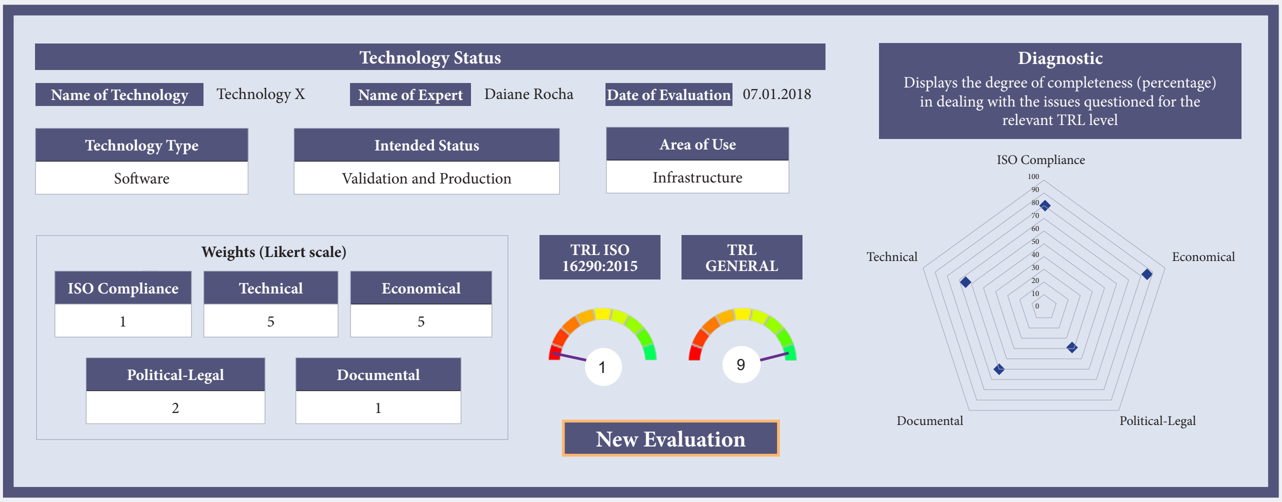
With the TRL results presented, for the projects analyzed here, it was possible to apply Δ TRL. Thus, one can see in Table 7 the TRL Δ found for each project.

Discussion

Technology maturity levels (TRL) provide a common understanding of the state of technology development. The assessment of technology maturity using the metrics occurs based on the state of progress of each technology. The benefits of using TRLs are related to better communication, results, and management of a research program (Araujo, 2020).

When comparing with the data obtained by Salgado (2016), through workshops and a reference table, we found that at the time, without the use of a TRL level analysis tool, the

Figure 10. **Technology Status**



Source: https://iae.dcta.mil.br/images/Calculadora_MRL_e_TRL/CalculadoraTRLIAEITA2020.xlsm, accessed 12.06.2022 (in Portuguese).

Table 5. **Evaluated technologies**

Technology	Description
1. MARIMBA	IAE project in the Materials / Defense sector, researched for 11 years, concluded in 2011. The project developed materials resistant to ballistic impact, for use in aircraft, helicopters and military vehicles. According to the project manager in an interview to evaluate this technology in TRL IAE / ITA-2016-1 Calculator, the technology targets TRL 9, but the process of transfer to industry has not been completed due to bureaucratic problems.
2. CARBON	Consists of thermostructural carbon composites reinforced with carbon fibers using hydroclavens. The simple compaction of reinforcing fibers, natural or synthetic, agglomerated with a binder material in the form of a thermosetting resin formulated with hardeners, forms lightweight materials structurally suitable for a variety of applications, bringing benefits to various industrial segments ranging from medical to aerospace.
3. L75	Consists of the design, manufacturing, testing and operation of a liquid rocket propulsion engine (liquid oxygen and kerosene). Technology of interest to the country described in the NAP, which aims to train it in the area of liquid propulsion, aiming to increase the capacity of launch vehicles to compete in the international space transportation market. In an interview to evaluate this technology in TRL IAE / ITA-2016-1 Calculator, the manager responsible for the technology aims to develop the prototype of the technology that is still in laboratory tests and in the research process, and aims to achieve TRL 5.
4. VSB-30	A sounding rocket, the result of a partnership between the IAE Institute and the German Aerospace Center (DLR) that funded part of its development. It is a certified vehicle. The qualification process for the rocket was evaluated by the European Space Agency (ESA), the DLR and the Swedish Space Agency (SSC), as well as the companies Kayser-Threde and EADS. The rocket has had seven successful launches: two in Brazil and five in Sweden. The VSB-30 aims at the transfer to the industry, since it is necessary and of political interest for scale production and to enable investments for the industry, since it is a certified product, with quality assurance. The certification consolidates VSB-30 as the best product in its category and one of the few in the world with a formal quality guarantee, issued by an internationally recognized competence body,» says the director of the Institute of Aeronautics and Space (IAE), Colonel Francisco Carlos Melo Pantoja. The delivery of the homologation certificate by the CTA's Industrial Promotion and Coordination Institute (IFI), according to Pantoja, also accelerates the process of transferring the vehicle's production technology to the Brazilian industry. Currently, several companies are working on its development and production: Villares, Cenic, Fibraforte, Mectron, Compsis, Avibrás, Orbital, among others.

Source: authors.

Garganta de Tubeira C/C project was classified as TRL 5, but when we applied the second version of the IAE/ITA TRL Calculator tool, the project showed a TRL 1 level.

Next, the Turbobomba and Câmara de Combustão projects, which are subsystems of the L75 MFPL and were being developed together, were analyzed. Both projects demonstrated TRL 4 and IAE/ITA TRL 4 according to NBR ISO 16290: 2015. When analyzing the results obtained by (Salgado, 2016), we found that both projects were from TRL 2 to TRL 4.

The analysis of the Net Propulsive Phase project resulted in TRL IAE/ITA - 2016 level1 and TRL 2 according to NBR ISO 16290: 2015. In the analysis performed previously by Salgado (2016), such project had presented TRL 2.

Through the results presented it is possible to verify that the use of the IAE/ITA TRL calculator tool, in addition to facilitating the application of the methodology, also makes the verification of the TRL levels of projects more accurate, especially when dealing with projects with low TRL levels.

The data collected by Salgado (2016) was obtained in 2014, while the TRL levels of the same projects using the tool were obtained in 2018. In the time interval between the completion of the two studies, we found that of the four projects analyzed here, only two managed to raise the TRL level: the Turbobomba and Câmara de Combustão projects, both of which grew two TRL levels in the period.

During the analyses, the commitment of project management to find budget sources and partnerships in order to meet the project schedule became clear, which likely contributed to the two-level increase of the TRL of these projects.

Regarding the Garganta de Tubeira C/C project, it was reported during the interview with the researcher that the stagnation of the project occurred due to a lack of partnerships with companies to realize the prototype, since DCTA does not have the infrastructure for its construction.

Regarding the Estágio Propulsivo Líquido project, it was reported that the Turbobomba and Câmara de Combustão projects are being prioritized to later focus on the development of the Estágio Propulsivo Líquido project.

Conducting the adaptation mitigated the issues raised in the research questions with the inclusion of questions pertinent to technological, economic, documentary, and political-legal issues. The evaluation process standardized, made feasible, and streamlined the evaluation process with the application given in Microsoft Excel. The validation of the methodology performed on the four technologies allowed us to analyze and adapt the methodology to the different contexts of the space and defense sector, with completed and ongoing projects and technologies with a systemic vision and basic technology. This research achieved its goal of expanding the

Table 6. **TRL analysis of the studied projects**

Project	TRL NBR ISO 16290:2015	TRL NBR IAE/ITA – 2016-1 Calculator	TRL (Salgado, 2016)
«Garganta de Tubeira C/C»	3	1	5
«Turbobomba»	4	4	2
«Câmara de Combustão»	4	4	2
«Estágio Propulsivo Líquido»	2	1	2«

Source: authors.

Table 7. **ΔTRL analysis of the studied projects**

Project	TRL_{Actual}	$TRL_{Desired}$	Δ TRL
«Garganta de Tubeira C/C»	1	5	4
«Turbobomba»	4	7	3
«Câmara de Combustão»	4	7	3
«Estágio Propulsivo Líquido»	1	7	6
Source: authors.			

knowledge of TRL and providing an adaptation in the process of evaluating TRL in technologies.

Conclusion

Due to the applications of the first version of the Calculator and the identification of the five points to be improved upon, the second version of the Calculator was created. The identified points of improvement were treated as follows:

Differentiation in the weights of the analyzed areas. All areas and all evaluation questions had the same weight in the TRL calculation for the first version. In the present version, it is possible for the respondent to put different weights on each area (Political-Legal, Technical, Documentary, Economic, and ISO). The weights are defined through a Likert scale, which defines five degrees of importance: 1 - Not important; 2 - Not very important; 3 - Moderately important; 4 – Important; and 5 - Very important. The weights impact the TRL calculations.

Bias in questions marked as ISO. In the previous version, the respondent could identify questions that counted towards the ISO Standard evaluation and questions that did not impact ISO. In the present version, the respondent is unable to identify which questions are or are not relevant to ISO.

Lack of clarity describing improvement and only containing the visualization of the result on the dashboard. There was an improvement process in the dashboard visualization of the final result, the inclusion of the radar chart with the Delta TRL proved to be of super importance because the respondent can identify which area he needs to improve and demand more effort to obtain the next maturity level.

Doubts in the understanding of some questions. The inclusion of a glossary for a better understanding of the questions in the manual proved to be very important for the respondents.

Difficulty when applying to technologies outside the aerospace sector. The generalization of the aerospace nomenclatures in the questions, the adaptation and inclusion of new questions, as well as a greater focus on becoming a project management tool made the tool's questions easier to understand and more applicable to other sectors.

Ultimately the tool, along with the application process, proved useful and replicable. The search for such a tool by government agencies and research institutions reinforces the need and feasibility of such a tool for this author. In Brazil, the maturity assessment is being requested in governmental agencies to incentivize and encourage research.

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New Approaches to the Improvement of Coordination Mechanisms

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Abstract

The intensity and scale of communication between people, which have grown significantly over the past three decades, have not yet led to comparable improvements in the coordination of the activities of socioeconomic agents. One of the reasons is the lack of a full-fledged digital transformation of coordination mechanisms. Therefore, an urgent scientific task is to determine methodological approaches for the full digitalization of coordination processes. Cognitive sciences offer a fundamental description of the processes of socioeconomic coordination in the form of a shared mental model of participants in joint activities. Based on this, the concept of coordinating the activity of agents, which is the basis of all coordination processes, is defined. This approach made it possible to identify and analyze the main elements of the fundamental process of coordinating activities, as well as to determine the opportunities for its digitalization. This paper discusses the opportunity to create a unified coordination mechanism based on computer technologies, which, on the one hand, could replace the traditional market and hierarchical mechanisms, and on the other hand, could be used to coordinate all types of joint activities, including non-economic ones.

Keywords: coordination of activities; contextual changes; hierarchies; mental model; mechanism of coordination; digitalization

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Introduction

The key modern socioeconomic development analysis methods are associated with the concepts of complexity, capabilities, and knowledge (Metcalfe, Foster, 2004; Antonelli, 2011; Fagerberg, Srholec, 2008). These terms comprehensively describe management systems applied to coordinate the interactions of agents. In this context, developing socioeconomic coordination models complements the existing techniques, and thus becomes a relevant objective. The coordination process has a complex structure, and manifests in various forms including hybrid ones (Powell, 1991; Malone, Crowston, 1994; Dementiev et al., 2017). Accordingly, such mechanisms are defined in academic literature in various ways.[1] Digitalization inevitably affects the functioning of coordination mechanisms, and if properly managed, can significantly increase the effectiveness of agents' interactions, thus providing an additional impetus to economic development (Nielsen, Jordanoski, 2020). To achieve this, it is first of all necessary to understand how coordination works at a fundamental level, and how it should be digitalized to obtain the desired positive effect.

A number of factors must be taken into account when planning coordination activities (CA): the common semantic environment which implies certain behavior rules and communication signals, data sharing options, prerequisites for the emergence of information images of the "partner family" members, conditions for finding collaboration options by testing the available possibilities based on individual and shared mental models, and criteria for making decisions about entering into a partnership.

At any given time, a certain number of options exist for each aspect. Their combinations determine the set of available CA configurations. Depending on the activity type, its context, and the number of partners involved, a scheme is chosen which provides maximum benefits for all participants. Most successful configurations created in particular areas are subsequently institutionalized in the form of general rules, which promotes their wide adoption. Thus, if the content of CA is known, their mechanisms can be improved upon by applying advanced information and communication technologies (ICT). Digitalization allows one to standardize certain CA elements, which partly smooths out the qualitative differences in relevant mechanisms (e.g. between market regulation and hierarchy). At the same time, flexibility in adapting CA to the activities of individual agents with the help of computer algorithms increases. It becomes possible to create a complex adaptive regulatory system, to replace multiple existing mechanisms with limited functionality.[2] This would allow for using resources more productively and enhance economic and social effects.

Approaches to Coordination in the Economy

Activities are coordinated in various formats and their combinations, which determines the variety of coordination measures. An agreement on joint work can be reached through a direct exchange of information. However, communication is often indirect in nature: agents observe the behavior of other participants in the common environment, and take it into account. Finally, following common behavior rules ensures the consistency of the steps taken, even in the absence of direct or indirect communications. Let us consider each format in more detail, with examples.[3]

Direct communication. The first approach views coordination as a result of direct dialogue between all participants in the process, and their agreements. Such "orchestration" allows one to divide responsibilities in the best possible way, and make sure they are carried out in a clear sequence. Regular dialogue and iterative adjustments of roles allow the team to flexibly respond to changes in the environment. In the literature, this approach is often referred to as *networking* (in the "everyone with everyone" format) (Powell, 1991; Provan, Kenis, 2008). However, in our opinion the term "network" does not accurately reflect its specific features. Any kind of agreement is based on relationships which can be presented as a network of links. Trust is more important here: the participant's subjective assessment of the likelihood that their partners or the team will follow the agreed upon plan (Adler, 2001). Therefore, the term "agreement" would be more suitable to describe this type of communication.

Another direct coordination type is delegating the right to decide who should be responsible for what to the manager. In this case an agreement is reached over the course of employee-manager interaction in the format of hierarchical (administrative) communication (Malone, Crowston, 1994; Weigand et

[1] An overview of definitions of the "coordination" concept can be found in (Weigand et al., 2003).

[2] A similar idea was discussed in our previous work in the scope of analyzing the properties of a perfect mechanism for coordinating socioeconomic activities and the conditions for designing it (Parinov 2020).

[3] There are numerous studies devoted to other aspects of coordination, in particular those on economic and complex systems; their reviews are presented in (Vlasova, Molokova, 2019; Khodakov et al., 2014).

al., 2003). Currently the agreement and hierarchical approaches are most often applied in combination (Powell, 1991; Malone, Crowston, 1994; Dementiev et al., 2017). For example, a member of a team of workers is given a job by the manager, and then the team members agree on the division of responsibilities. In turn, the managerial decision can also be made collectively (by a board of directors, etc.).

Indirect communication. Here we are talking about the interaction between agents who cannot or choose not to share information directly. They observe each other's activities in a common semantic field, including the internet environment. Traces of their activities (special markers, etc.) may contain detailed information for other agents' behavioral decisions. This format is often referred to as *stigmergy* (Elliott, 2006; Marsh, Onof, 2008; Elliott, 2016; Heylighen, 2016). A particularly bright example of coordination partly implemented through indirect communication is the interaction of market players in the context of trading and negotiating prices. Buying and selling operations leave a trail that affects the prices of goods, which in turn encourages further transactions (Heylighen, 2016). One of the motivators in this case is competition (Polterovich, 2018). Further on we will use the term "stigmergy" to refer to this format, and assume that market coordination is a hybrid approach which includes stigmergy, agreement, and hierarchical formats (Powell, 1991; Malone, Crowston, 1994; Dementiev et al., 2017).

Following the rules. Behavior rules, explicit and implicit norms, and generally accepted cultural attitudes allows "network" participants to act smoothly even without communicating with each other. This is the case when precedent actions are taken into account by other agents by default, e.g., when they use public benefits.

All of the above approaches can be used in parallel or in combination. In practice, a complex multilayer system of various, qualitatively different coordination processes emerges.

Developing an Integrated Coordination Mechanism

The main problem a systemic study of diverse coordination formats faces is identifying the basic principles of this process, formulating them, and designing approaches to their analysis (Malone, Crowston, 1994). The existing theoretical models and methodological tools are not enough for solving it. A universal coordination mechanism must be developed, along with structured approaches to assessing the available alternatives and choosing among them (Crowston et al., 2015, p. 29). In our opinion, these objectives can be accomplished if we consider the coordination processes from the standpoint of specific actors' behavior, and on the basis of the latest cognitive sciences advances, in particular the mental model concept (Johnson-Laird, 1980; Mantzavinos et al., 2004; Badke-Schaub et al., 2007).

A mental model is defined as a mechanism for describing the system, its purpose, forms, and operation, assessing its current state, and forecasting future ones (Mathieu et al., 2000). The "team mental model" concept reflects the implicit coordination characteristics of effective teams and expands the understanding of how they operate in complex, uncertain, and rapidly changing situations (Mohammed et al., 2010). The prerequisites for identifying basic principles and developing a comprehensive definition of coordination are built on the fact that in the mind of an individual agent, all the diversity of its forms merges into a single system. This synthesis is supported by a mental model, since by definition it embraces all the collaborative activities the participant is involved in, and the perceived interdependencies between them. In the understanding of an individual, all coordination processes are combined by a certain specific CA, which allows the individual to build a mental model in their mind, containing information images of their counterparts' capabilities and intentions. The model allows one to calculate the interaction options and select the best one for the implementation (sometimes jointly with partners[4]). Due to the involvement of other players, coordination, along with the main activity, becomes a joint process for them, which takes several forms. Each participant accumulates data on the actions of other actors in the common environment, leading to the emergence of information images in their mind, which are updated as new information is received. The actual content of these ideas also depends on the effectiveness of other players' participation in the CA, whose images must be adapted to the specific features of a particular activity type. The effectiveness of coordination depends on the consistency of various information images, which must have certain common features for the same type of joint activity (Table 1).

Partners' information images become a part of the mental model of the context where the agent operates, along with other information related to his/her activities. They encode information about the dynamics of the business environment, strate-

[4] The processes of coordinating joint activities on the basis of agents' mental models described in this and the following sections are based on the system of hypotheses and their consequences presented in (Parinov, 2020, pp. 11–19).

Table 1. **Characteristics of Agents' Information Images, Collaboration Types**

Partnership type	Information images' characteristics
Agreement	Can realistically describe agents' status due to direct information sharing
Hierarchy	Contain agents' professional characteristics, describe their competencies and responsibilities
Market regulation	Agents' images are represented by products and services they offer, the prices of which are adjusted by the interplay of supply and demand.
Following common rules	Not applicable, because no communication between agents takes place
Source: author.	

gies for responding to external changes, collective goals, and participants' interdependence (Salas et al., 2005). As a result of agents' active interaction in creating and updating their individual mental models, a common configuration of joint activity naturally emerges (Badke-Schaub et al., 2007). By continuously sharing information in the "everyone with everyone" or "worker-manager" format, participants maintain in each other's minds an up-to-date understanding of both the current state of affairs, and individual strategies, which allows for anticipating partners' actions and estimating the amount of resources needed to implement the plans (Mathieu et al., 2000). By developing a common mental model, team members can interpret information in the same way, share visions of the future, and identify causal relationships (Mohammed et al., 2010). As a result, each of them obtains a more complete picture of the environment they act in, and of the changes occurring there. The team mental model "works" under a certain set of conditions, including mutual trust and "closed" communications (Salas et al., 2005). As was noted, an individual mental model allows the agent to analyze possible interaction options and choose the best one in each situation. In a team format, a mental model facilitates the analysis of group strategy options, the choice of the most suitable one for all team members, and its implementation.

An effective coordination "flow" largely stems from self-organizing processes inherent in complex systems, with their flexibility and a wide range of possibilities. Adjusting such processes requires taking several aspects described in Table 2 into account, and their combinations. By analyzing the changes in the external environment, status, and behavior of other players, the agent chooses the cooperation format and adjusts their strategy. Thus, the consistency of joint activities in a changing environment is achieved and maintained.

The practical application of each tool may vary depending on the context. Therefore, a variety of CA configurations inevitably arises, with different efficiencies. The efficiency depends on cooperation features (number of participants, activity type, and conditions). But whichever configuration is chosen, adjusting it to achieve the desired performance will take a significant amount of time. During that time unpredictable changes can occur in the external environment, leading to its transformation. We would like to reiterate that coordination processes cannot be updated without adjusting agents' mental models. If mental models' updating lags behind the rate of contextual changes, the models lose relevance, so the agreement process must be restarted.

Thus, two main factors of any CA configuration's effectiveness can be singled out: the speed of processing information available to players and the pace of external changes, which devalue the shared information. To discover and assess context changes, real-time data processing tools are needed, which increase the chances to proactively adapt

Table 2. **Tools to Support Coordination Processes**

Tool	Description
1. Signal system	Informs participants about ongoing processes, partners' resources and strategies, and general behaviour rules.
2. Communication format	Communications can be direct, indirect, or hybrid, depending on the specific activity, its context, and agents' natural abilities.
3. Participants' information images	Based on them, agents draw conclusions about each other's capabilities and intentions, and specific features of the communication environment. The dependence on other agents' images, accuracy, completeness, and relevance in reflecting the actual status of each of them are assessed.
4. Mental models	Applied to choose cooperation options. Individual models involve "calculating" the options in one's own mind, while team ones - making decisions jointly with other players.
Source: author.	

to changes. A configuration which allows one to secure maximum advantages when taking into account the specifics of a particular activity type, available analytical resources, and the frequency of hard-to-predict changes seems to be optimal. If such optimized structures are constantly improved and follow uniform rules, over time they turn into an institutional basis for coordination processes, which reduces the costs of managing them.[5]

The above analysis suggest it would be possible to develop a universal approach merging various coordination formats. The structure described above is proposed as a basis, since it is present in all coordinated systems and can be applied in different configurations, depending on the nature of the main activity and the specific context.[6]

Thus, coordination processes (and their object, the core activity) involve the interaction between agents, and in their turn are subject to "orchestration" of a higher order.

Digitalization of Coordination Processes and its Effects

Digitalization transforms cooperation networks: a distributed global online system emerges, which significantly increases communication capabilities. Its further development requires the improvement of signal systems and behavior rules. A common virtual space will allow all agents, regardless of their geographical location, to make a full use of the coordination potential of advanced information and communication technologies. The digitization of information images implies the introduction of computer interfaces, by using which actors would present and update information about their intentions and options. Software tools are being improved to facilitate the processing, mutual synchronization, and distribution of these images among potential participants. The use of such tools increases the effectiveness of coordination, depending on the activity type and its context.

Software modification allows for fine-tuning digital images, while the complex task of coordination is adapted to the context of interaction between a particular group of agents. The interaction parameters are individually adjusted for each of them, depending on their resource potential and objectives. Computer monitoring of changes in the participants' information images and in the environment promptly sends signals about the emergence of obstacles hindering cooperation and the need to revise the latter's format. Thus, despite external changes, the "orchestration" of activities is dynamically maintained. Modern ICT allows one to integrate digital images into a unified system. On their basis, online services and simulation tools are created, to evaluate possible partnership options. The range of criteria taken into account to choose effective cooperation modes expands significantly. Individual understanding of changes in the external environment, behavior, and status of other participants becomes deeper. The digitalization of CA simplifies cooperation to the maximum possible extent and increases its efficiency. All coordination mechanisms merge into a global simulation model which is interactive, realistic, and flexible. It involves both active agents and digital twins of the objects they interact with. Various coordination types (agreement, hierarchy, stigmergy) acquire common features and can be used by teams regardless of the geographical location of their individual members. All processes are implemented through computer interfaces and algorithms, which, *ceteris paribus*, allow one to achieve higher coherence than under traditional approaches, accomplish more complex management objectives, and increase the maximum number of interaction participants. It becomes possible to change the coordination type or use complex hybrid combinations based on optimized recommendations made by the digital system.

Prerequisites for the Development of a Unified Coordination Mechanism

Profound integrated digitalization is gradually erasing the qualitative differences between the main coordination types, while their elements are being normalized. In the virtual environment, mental projections of agents' information images common for the agreement coordination format turn into digital objects alienated from the consciousness that created them. Software algorithms provide more advanced mechanisms for designing both individual and team mental models.

Modern ICTs allow for no less thorough direct communication than in a real environment, and given the absence of geographical limitations, the scope for sharing information significantly increases. In the case of market coordination, the digitization of images and activity traces eliminates the severe restrictions on the communication format typical for the stigmergic approach, since in a virtual environment it can easily be conducted both indirectly and directly.

[5] Traditional coordination mechanisms (agreement, hierarchy, and market ones) have developed in a similar way.

[6] For a detailed description of variations of the elements that make up the agreement, hierarchy, and market coordination formats, see (Parinov, 2021, pp. 13–19).

Digital transformation of information images allows agents to maintain as complete and up-to-date profiles in a common virtual space as possible, with the help of computer interfaces. Simplified versions of images can be automatically generated without agents' direct participation, depending on their role in the joint work.

The agents' CA is fully implemented in a shared virtual environment. Regardless of the cooperation format, it is regulated by a signal system and behavior rules uniform for all participants. Instead of direct and indirect communications in the traditional sense, actors use universal digital communication mechanisms to inform each other about their goals and capabilities. They create and update the most accurate digital images of themselves. The system algorithmically selects simplified versions of these images and possible connections between them (e.g. hierarchical ones) taking into account the type of joint activity. On this basis, a selection of the best cooperation options is generated, providing the highest combined benefits for all participants, which serves as a starting point for making decisions about individual contributions to a joint activity.

The digital transformation of CA leads to the unification and reduced diversity of its elements. As a result, different coordination formats, e.g., agreement and stigmergy, converge in terms of the process content, which substantially simplifies the division of responsibilities between individual participants. The same steps become applicable to different types of cooperation, while in the pre-digital era applying them would require more complex, multidirectional efforts. Due to unification, agents' CA are reduced to collecting information in the virtual and real environments, updating their images, and choosing between the cooperation options offered by the system. All other elements are performed by computer software.

Taken together, the described processes open theoretical possibilities for designing and implementing an all-purpose global coordination mechanism, whose structural elements, properties, and principles have yet to be explored. The main benefits of adopting such a system are that instead of several disparate decisions, actors would have a unified adaptive mechanism which would increase the efficiency of activity coordination, including in the framework of the international division of labor. Software interfaces would play the role of institutional regulatory structures ensuring agents' compliance with specified rules, while also increasing the possibilities for their self-realization. All participants in the global economy become their potential partners, while the strategic goals of and resources for joint activities are presented in a more complete and qualitative manner.

The distributed global online system created as a result of the digitalization of CA will allow for coordinating any activity types. Interconnected, systemic coordination in the economy, science, socio-political, and educational spheres, and in the field of security among other areas will help accomplish individual goals through the adoption of a unified mechanism. Unique opportunities for realizing human potential to promote economic and social development are opening up.

Conclusion

The coordination of actions precedes obtaining results from any socioeconomic initiative, therefore, coordination mechanisms significantly affect such initiatives' outcomes. The former can be improved with digital technologies, the potential of which, however, has not yet been fully realized. Nevertheless, digitalization seems to be a necessary condition for "upgrading" management systems further.

The paper considers the possibility of creating a unified coordination mechanism as a logical consequence of digitalization and the unification of its elements. The development of such a toolkit will facilitate the coordination of various activity types, help to better harmonize the interests of various groups, and more efficiently consolidate the efforts taken to meet global challenges.

Further research will allow one to assess the potential of advanced ICT in improving various types of partnerships and their performance. The versatility of CA as a tool for optimizing any cooperation format opens the possibility to develop a unified ICT-based coordination platform, adaptable to the particular conditions of agents' interactions. These research areas will provide a key to understanding the properties of the post-digital development stage of the economy and society, most important aspect of which is the digital transformation of regulatory mechanisms and the associated social changes.

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