Deep-tech entrepreneurship in Spain

Understanding a complex problem
Working Paper

Oihana Basilio Ruiz de Apodaca – MIT-Rafael del Pino Fellow (2020-2022)

Fiona Murray – William Porter Professor of Entrepreneurship & Associate Dean for Innovation + Inclusion, MIT School of Management

Lars Frolund – Lecturer, MIT Sloan School of Management

About the Authors

Oihana Basilio Ruiz de Apodaca

MIT-Rafael del Pino Fellow (2020-2022)

Dr. Oihana Basilio Ruiz de Apodaca is the MIT-Rafael del Pino Fellow (2020-2022). She is Assistant Professor at the Autonomous University of Madrid, where she teaches and researches on issues related to innovation, knowledge management and leadership communities. She was the Director of Research and Online Programs at the Rafael del Pino Foundation from 2015 to 2020 and, previously, the Director of Celera (2014-16), an association devoted to the acceleration of Spanish young talents. She holds a PhD in Economics and a MSc in Economics and Management of Innovation from the Autonomous University of Madrid, a MSc in Society, Science and Technology from the European Inter-University Association, a MA in Musicotherapy from ISEP, and a Bachelor's Degree in Economics from the University of the Basque Country, where she grew up.

Dr. Lars Frolund

Lecturer, MIT Sloan School of Management

Dr. Lars Frolund**'s** expertise lies at the intersection of mission-driven innovation, grant **and** venture capital investments into deep tech ventures, and building innovation ecosystems. Most recently, he was Special Advisor at NATO HQ for the creation of the Defense Innovation Accelerator for the North Atlantic (DIANA) and NATO's One Billion EUR Innovation Fund – the world's first multi-sovereign venture capital fund. Formerly, Dr. Frolund was Research Director, Visiting **Fellow,** and a Fulbright Scholar at the Massachusetts Institute of Technology (MIT) where he now currently serves as a Lecturer. He also serves on the board of directors of the European Innovation Council (**Europe's** largest investor into deep tech ventures) and the Danish Innovation Fund (**Denmark's** largest investor into deep tech ventures). He lives in Copenhagen with his family.

Fiona Murray

William Porter Professor of Entrepreneurship & Associate Dean for Innovation + Inclusion, MIT School of Management

Fiona Murray is the William Porter Professor of Entrepreneurship and Associate Dean for Innovation + Inclusion at the MIT School of Management. Fiona is also a Fellow-in-Residence at The Engine. She is an international policy expert on the transformation of investments in science and technology into deep-tech start-up ventures that solve significant global challenges and create national advantage - from defense and security to health, food, and water security. She serves on the UK Prime Minister's Council for Science and Technology and is a member of the UK Ministry of Defence Innovation Advisory Panel. Fiona received her BA and MA from the University of Oxford in Chemistry. She subsequently moved to the United States and earned an AM and PhD from Harvard University in Applied Sciences.

Foreword

Innovation and technological progress are crucial factors in resolving the problems and the challenges that affect us; they also are fundamental in the transformation of our economies, and improving competitiveness in the medium and long terms.

The recent crises caused by the pandemic and the war in Europe are testing us again and are requiring the design of innovative measures to cushion their impact. Technology has been a key aspect in this shared effort. In the coming years, technological development will continue to increase with the corresponding demand and competition for talent and knowledge becoming more acute as these new technologies progress. In order to successfully meet the extremely complex and multidimensional challenges we face, it will be necessary to activate and support a multiplicity of actors, new leadership will be necessary.

With the aim of providing ideas and sound arguments to drive Spain on the path of growth through science, innovation, technological progress, and business activity, the Rafael del Pino Foundation and MIT Sloan agreed to launch the Rafael del Pino-MIT Innovation Initiative Fellowships on Deep Tech Entrepreneurship, whose first fellow was Professor Oihana Basilio Ruiz de Apodaca. The result of her research, co-directed by professors Fiona Murray and Lars Frolund, which is summarized in this report, analyzes the strengths and the weaknesses of the Spanish entrepreneurial ecosystem with respect to Deep Tech.

This reports formulates a series of recommendations with the aim of creating a critical mass of adjustments that would allow in Spain, a consolidation of an effective system that promotes the development of Deep Tech entrepreneurship.

The publication of this report is opportune, as it comes to light during a period of disruption, a dynamic and interesting time from an economic and technological point of view. Additionally it is pertinent, as it will help us to better understand the assets that Spain has in the field of deep technologies, along with identifying the main obstacles faced by our scientists, businessmen, and public administrators that are impediments in positioning Spain in a leadership role in this field.

We conclude these brief lines by thanking Oihana Basilio, Fiona Murray and Lars Frolund, for their efforts, together with MIT Sloan and the Foundation, for promoting innovation and disseminating knowledge in Deep Tech. Our heartfelt thanks also, to all of the experts interviewed, for their selfless collaboration. And to all of you, we hope that you will find this work stimulating and providing ideas to improve the practice of innovation and entrepreneurship in deep technologies.

Vicente J. Montes Gan

Director

Fundación Rafael Del Pino

David Capodilupo

Assistant Dean for Global Programs

MIT Sloan School of Management

Table of Contents

Excecutive Summary

This report analyzes the strengths and weaknesses of the Spanish deep-tech ecosystem by applying the MIT iEcosystem model, which emphasizes five critical system inputs (i.e., human capital, funding, infrastructure, demand and culture/incentives) driving innovation capacity (I-Cap) and entrepreneurship capacity (E-Cap). The assessment of these inputs, both strengths and weaknesses, serves as the basis for key recommendations designed from a systems perspective to strengthen Spain's deep-tech ecosystem. The MIT approach also emphasizes the role of cocreation and collaboration among key stakeholders (i.e., entrepreneurs, venture capitalists, universities, companies, and the government) as an approach to implementation. In addition, the report sets out to create an international benchmark of deep-tech plans based on other developed countries as an opportunity to compare current and future actions in Spain.

The report's recommendations aim at creating the necessary critical mass to foster deep-tech entrepreneurship, as key factor i the competitiveness of the country.

The recommendations are to create:

1) An **explicit Spanish deep-tech strategy** (led and developed by the government).
2) A **Spanish Association of industrial deep-tech clients** (led by corporations).
3) A **national club of deep-tech investors** (led by venture capitalists).
4) An **official deep-tech entrepreneurship and innovation school** (led by Universities and PROs).
5) A **deep-tech entrepreneurship summit** (led by entrepreneurs).

1 Introduction

Technological power and innovation shape economic competitiveness and geopolitics and hence, can be critical to economic dominance, a race in which the US and China are taking the lead, leaving Europe behind. In this context, innovation-driven deep-tech entrepreneurship has a high potential for impact and value creation, both directly and indirectly, both advancing the technological frontier with new products and services and transforming existing industrialization processes for modern, clean growth. In fact, Budden and Murray (2018) state that innovation-driven enterprises (IDEs) are a style of entrepreneurship with "*the potential for extraordinary job creation and the aim to develop solutions to important problems"* as opposed to more traditional and locally focused small/medium-sized enterprise start-ups. Within this category of IDEs, and as emphasized by the report "*Deep-tech: The great wave of innovation*" (De la Tour, Portincaso, Goeldel, Chaudhry, Tallec and Gourévitch, 2021), deep-tech ventures are revolutionizing the innovation landscape and "*making the impossible possible, fast*" in fields that used to be an area of competition among states (e.g., nuclear fusion or space exploration).

Because of their relevance for economic competitiveness and their proven contribution to solving important societal challenges, investment in deep-tech startups and scale-ups quadrupled between 2016 and 2020, growing from $15B to $60B. Corporations have increased their investments in deep-tech ventures, and funding sources have expanded (De la Tour et al., 2021). Similarly, many developed countries have established initiatives to promote deep-tech entrepreneurship (Hafied, 2022).

However, the definition of "deep-tech" is not self-evident and has often been ambiguous (Basilio, Murray and Frolund, 2022), with studies focusing on the sector to which a technology belongs rather than its immutable characteristics. We develop our definition of deep tech more extensively in a short accompanying note. However, for the purposes of this document, we largely emphasize the definition from De la Tour, Soussan, Harlé, Chevalier and Duportet (2017): ventures with a strong research base, "*based on disruptive solutions built around unique, protected or hard-to-reproduce technological or scientific advantages*", with long R&D cycles and much uncertainty. Moreover, they are characterized by four main attributes (De la Tour et al., 2021):

1) Problem-oriented rather than technology-driven (97% of deep-tech ventures contribute to at least one of the UN's sustainable development goals).
2) Situated at the convergence of technologies (96% of deep-tech ventures use at least two technologies).
3) Building on the advancements of the digital revolution but developing mainly physical products (83% of deep-tech ventures are building products with a hardware component).
4) Deeply interconnected with the innovation ecosystem (e.g., universities and research labs are closely involved).

From this definition, we can deduce that transformation from deep-tech-relevant knowledge to economic growth faces barriers that "*inhibit the conversion of knowledge produced in R&D laboratories of incumbent firms and in universities into commercialized knowledge*" (Ghio, Guerini, Lehmann and Rossi-Lamastra, 2015: 9) and impede the transformation of knowledge into marketable products (Jarchow and Röhm, 2019). Moreover, positioned at the knowledge frontier, deep-tech ventures have higher technology risks and complexities. In addition, deep-tech ventures are often made up of tangible (physical) components and hence, require heavy production processes, involve complex certification, are more difficult to scale, and require higher capital intensity (De la Tour et al. 2017).

As a result, deep-tech firms face significant frictions, barriers and at times, market failures and hence, are affected by a deficit of private initiative (especially capital) that justifies the intervention of the state (Hafied, 2022). However, designing the types of policy initiatives and actions that promote deep-tech entrepreneurship is especially complex for different reasons (Budden and Murray, 2018) that add to the specific challenges already mentioned:

1) Innovation takes place in complex systems, and hence, there is no single bullet or singular magic solution, as "complex problems require complex solutions".

2) Any strategic intervention requires a deep understanding of the innovation ecosystem.

3) The different tiers of governance involved in innovation policy add complexity, which is relevant for the design and implementation of actions.

4) Effective innovation depends on the involvement of many key stakeholders, namely, industry, venture capital, entrepreneurs and academia.

If Spain aims at remaining competitive in the new international context (García, 2021) and in the so-called 4th wave of innovation (De la Tour et al., 2021), the promotion of deep-tech entrepreneurship is especially relevant for the country, ranked as a "moderate innovator" in the 21st position of the European Innovation Scoreboard 2021 (European Commission, 2021). Acknowledging this challenge, Spain will receive up to

140.000 million euros for reforms and investments coming from the "Next Generation EU" funds[1], which offer a unique opportunity for the country to define a new paradigm for innovation and entrepreneurship based on deep technologies.

The **objectives of this analysis** are as follows:

- **To understand the main strengths and weaknesses** of the Spanish innovation ecosystem for the fostering of this specific type of deep-tech innovation and entrepreneurship from a systemic and multistakeholder point of view.
- **To offer a picture of the main policies and initiatives** being implemented in Spain for the promotion of deep tech.
- **To develop recommendations for the fostering of deep-tech innovation and entrepreneurship in Spain directed to the key stakeholders of the ecosystem**, that is, actions that can be implemented not only at the macrolevel by the government but also at the microlevel by specific institutions and stakeholders[2].

The following sections aim at excavating all these issues and understanding the Spanish ecosystem as a necessary condition for designing adequate and systemic actions.

2 Methodology

2.1. Methodological and analytical framework

Understanding entrepreneurship and entrepreneurial behaviors requires the analysis to be situated within a comprehensive theoretical framework, which includes the social, cultural, political and economic context (GEM Spain, 2021). This context creates the specific country conditions and the conditions for the entrepreneur, as it includes basic requirements (e.g., educational opportunities, infrastructure, appropriate institutions), other characteristics that promote efficiency (e.g., funding for technology at different stages and demand signals from customers), as well as other requirements related to innovation and entrepreneurship, such as awareness of public policies and social and cultural norms, which interact and affect other individual factors.

The "**MIT framework for innovation ecosystem policy**" (see Appendix 1 for a detailed description of the framework and the literature review supporting it) has been used to assess the concrete areas of weaknesses (and strengths) of the Spanish deep-tech ecosystem. First, the MIT framework was produced at the request of policy-makers and developed by Budden and Murray (2018) along with REAP (regional entrepreneurship acceleration program) colleagues to specifically assess the conditions that support the startup and growth of innovation-driven enterprises (IDEs). Hence, the framework provides a tool to drive not only reflection but also action and has been successfully applied to different real cases (e.g., Person, Cohen, Miller and Murray, 2019) and locations as varied as the US, Tokyo, Singapore, Finland Israel, London or Morocco (Budden and Murray, 2018). Second, the framework outlines critical system inputs into innovation capacity (I-Cap, i.e., the capacity of a place to develop "new-to-the-world" — or to the country — ideas and to translate science and research "from inception to impact" by

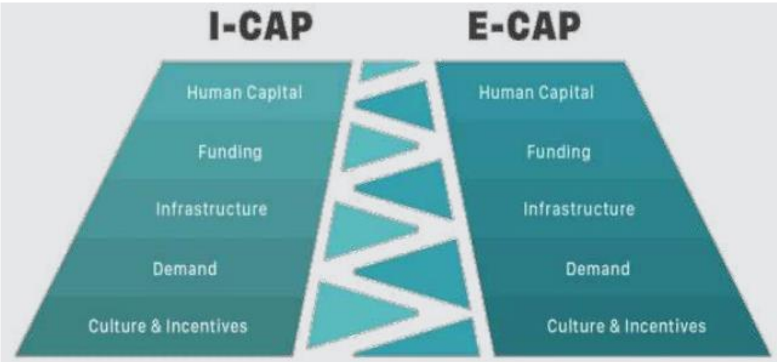
[1] https://planderecuperacion.gob.es/politicas-y-componentes

[2] For example, the Rafael del Pino Foundation (https://frdelpino.es/), the Spanish NPO funding this research, is interested in designing specific initiatives directed toward the promotion of deep tech.

transforming it into solutions that truly solve problems) and entrepreneurship capacity (E-Cap, i.e., the more general capabilities and conditions for creating enterprises). Hence, the framework identifies specific areas for the collection of data and analysis and for the development of actions. Third, it emphasizes the need for collaboration between different agents of the ecosystem and hence, provides a comprehensive perspective for analysis.

In other words, the *MIT iEcosystem framework* offers a comprehensive yet simple understanding of the system that allows for the creation and growth of IDEs by decomposing the system into four elements (i.e., the foundational institutions, the two critical capabilities I-Cap and E-Cap, the comparative advantage of a region's economy, and the generated impact). Within these elements, it is the combination of and linkages between I-Cap and E-Cap within a country that are critical, and to optimize these capabilities, five categories of system inputs are defined: 1) human capital, 2) funding, 3) infrastructure, 4) demand and 5) culture and incentives (Figure 1). At the same time, within each dimension, a variety of policy levers can be used to enhance access to these necessary resources.

Figure 1: Drivers of I-Cap and E-Cap



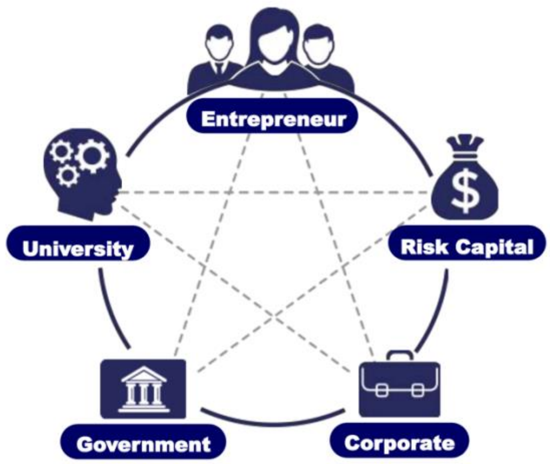
Source: Budden and Murray, 2018

The components of the *MIT iEcosystem framework* have been applied as conceptual and analytical parameters for gathering data for analysis, taking into consideration that the promotion of deep-tech ventures requires a special kind of I-Cap (e.g., with high R&D intensity and other specific challenges, such as longer times-to-market and higher capital intensity). Deep-tech ventures are also delimited by a special kind of E-Cap and entrepreneurs (e.g., with a problem-oriented focus, deep interconnections with the ecosystem and a strong appreciation of complex technology).

In addition, transformation from knowledge to economic growth can take place outside the source of knowledge creation (e.g., universities), that is, by economic agents that are not necessarily the inventors –, i.e., the E-cap and associated entrepreneurs are a special type of economic actor. These agents (e.g., entrepreneurs and other intermediaries, such as deep-tech venture builders) must act as catalyzers of the process (Braunerhjelm, Acs, Audretsch and Carlsson 2010) and hence, play a crucial role in technology development and innovation-driven entrepreneurship.

The MIT iEcosystem framework recognizes that effective innovation depends on social cohesion, collective action and the involvement of many key stakeholders (Budden and Murray, 2019). Specifically, *MIT's stakeholder framework for building and accelerating innovation ecosystems* enables understanding the systemic roles played by the five key stakeholders required for building innovation ecosystems: corporations, venture capital, entrepreneurs, academia and government (Figure 2). In addition, other actors also play an important role in the ecosystem, such as specialized service providers (e.g., lawyers, consultants), nongovernmental organizations, civil society, and founders of accelerators and sandboxes, etc., often sponsored by one or a mix of the five described stakeholders.

Figure 2: MIT's five stakeholders in an innovation ecosystem



Source: Budden and Murray, 2019

This framework emphasizes that each of the mentioned stakeholders is necessary in the innovation ecosystem but not sufficient by themselves. In contrast, there is a need for cohesion and collective action among them, and "*their engagement must be more than simply a measure of their presence in the ecosystem*" but actual participation in innovation ecosystem-building activities (ibid). As a consequence, we considered this multistakeholder approach not only in the process of data collection and analysis but also in the proposal of actions to take.

2.2. Data collection and analysis

The analysis of the five categories of inputs or drivers of I-Cap and E-Cap for deep-tech entrepreneurship in Spain has been based on a combination of quantitative and qualitative data, as this mixture of typologies provides a more comprehensive picture of the complex problem.

Our methodology consisted of a) open research, based on literature reviews and the analysis of specific country reports, b) direct data and document requests from different institutions, c) semistructured interviews with Spanish deep-tech entrepreneurs from different industries and different entrepreneurial journeys (e.g., originating from science or from industry), and d) semistructured interviews with other Spanish experts from the remaining four key stakeholder categories (i.e., representatives from universities, venture capital groups, government and corporations, and other "*mixed*" actors such as corporate-government deep-tech venture builders).[3]

After an extensive review of wider literature in the context of the MIT framework, we conducted 11 interviews with deep-tech entrepreneurs of different industries with different scientific and technological backgrounds and 8 interviews with experts involved with deep-tech venture activity, including deep-tech investors, professors and heads of supporting institutions (see Appendix 2 for the profiles of the 19 interviewees). We have given special importance to the perspectives of entrepreneurs on the current

[3] We have reviewed academic literature on entrepreneurship education (Basilio and Gabaldon, 2021) and technology transfer (Jarchow and Röhm, 2019; Siegel, Waldman and Link, 2003), public documents and publications related to deep tech (De la Tour et al. 2017; Hafied, 2022), specific country reports (OECD, 2021; GEM Spain, 2021), relevant policies (e.g., public institutional webpages) and statistical data (European Commission, 2021). The analysis of this secondary information has allowed us to identify gaps to fill.

ecosystem and necessary policies so that proposed policy can be targeted toward real needs and not just "*what we imagine that a deep-tech entrepreneur needs*" (Budden and Murray, 2019). Hence, special attention has been devoted to the different entrepreneurial journeys experienced by deep-tech entrepreneurs and to their perceptions of encountered barriers and catalysts.

The interpretation of results has been classified into the five components or drivers of the *MIT iEcosystem framework*. Finally, our interpretation of results has been reviewed and triangulated by innovation experts deeply familiar with the Spanish deep-tech innovation system and relevant European initiatives[4], who provided important insights and additional feedback, specifically regarding benchmarks for national and international policies.

3 Findings for Spain

3.1. Spain in the context of European innovation and deep tech

According to the most recent European Innovation Scoreboard, Spain is considered a "moderate innovator" within the EU, with important structural differences that impact both its I-Cap and E-Cap (Table 1).

Table 1. Structural differences between Spain and the EU impacting I-Cap and E-Cap

Performance and structure of the economy	ES	EU
GDP per capita (PPS)	28,300	30,800
Average annual GDP growth (%)	-5.3	-2.5
Employment share Manufacturing (NACE C) (%)	12.6	16.5
of which High and Medium high-tech (%)	31.8	37.9
Employment share Services (NACE G-N) (%)	48.5	41.2
of which Knowledge-intensive services (%)	31.4	35.1
Turnover share SMEs (%)	38.4	36.5
Turnover share large enterprises (%)	40.0	45.7
Foreign-controlled enterprises – share of value added (%)	9.8	11.8
Business and entrepreneurship		
Enterprise births (10+ employees) (%)	1.4	1.0
Total Entrepreneurial Activity (TEA) (%)	6.2	6.7
FDI net inflows (% GDP)	2.7	2.0
Top R&D spending enterprises per 10 million population	4.4	16.2
Buyer sophistication (1 to 7 best)	3.5	3.7

Innovation profiles	ES	EU
In-house product innovators with market novelties	6.2	10.7
In-house product innovators without market novelties	7.1	12.3
In-house business process innovators	10.6	11.0
Innovators that do not develop innovations themselves	3.5	11.6
Innovation active non-innovators	2.8	3.3
Non-innovators with potential to innovate	43.2	19.9
Non-innovators without disposition to innovate	26.6	31.3
Governance and policy framework		
Ease of starting a business (0 to 100 best)	77.8	76.5
Basic school entrepreneurial education and training	2.0	2.0
Govt. procurement of advanced tech. products	3.2	3.5
Rule of law (-2.5 to 2.5 best)	1.0	1.1
Climate change indicators		
Circular material use rate	9.6	11.7
Greenhouse gas emissions intensity of energy consumption	83.8	86.6
Eco-Innovation Index	104.0	100.0
Demography		
Population size	47.0	446.7
Average annual population growth (%)	0.7	0.1
Population density	93.2	108.8

Source: EIS 2021, European Commission (2021)

In relation to **I-Cap**, the Spanish innovation index shows a normalized performance that is predominantly weak in comparison to the EU levels[5].

[4] In this regard, we want to acknowledge the contributions of the Senior advisor at the Office of the Minister for Science and Innovation, José Guimón de Ros, and of Faÿçal Hafied, former Deputy head of the office in charge of developing innovation policies in France (including the French "Plan Deep Tech" initiated in 2018 and to which this paper refers), at the Direction Générale du Trésor (French Treasury) in the service of the French Minister of Economy.

[5] The Spanish indicators for 2021 are yellow (between 70% and 100% relative to that of the EU) in the following areas: attractive research system, finance and support, use of information technologies, linkages and intellectual assets. The indicators are orange (below 70% relative to the EU) in the following areas: firm investment, innovators, and employment impacts (European Commission, 2021).

Human capital: Spain has strong, above average results in the number of doctorate holders and the proportion of population with tertiary education. Spain also excels in scientific production; the country is ranked twelfth in the world and fifth in Europe (The Collider, 2019). However, while STEM (*Sciences, Technology, Engineering, Mathematics*) skills appear crucial in launching deep-tech projects (Deming, 2019), training in these areas is decreasing in Spain[6], and the orientation toward these subjects in higher education is also lower than that in other EU countries (Spain had a rate of 20,9 per thousand higher education graduates in science subjects in 2019, compared to 27,5 per thousand in France and 24,4 per thousand in Germany, and the EU-27 average of 20,8 per thousand[7]). The number of PhDs has increased significantly in Spain since 2013 (from 25.000 to 75.000 individuals) but remains far below countries such as the UK (110.000) and Germany (200.000). Moreover, the majority of young Spanish PhDs graduated in medicine, humanities and social sciences rather than in mathematics and information sciences (only 31% of PhDs)[8].

Funding: Importantly for deep-tech innovation, R&D expenditures in Spain are below EU levels both in the public and business sector (65,5% and 46,1% relative to the EU, respectively) and have been decreasing since 2014. In addition, the role of the business sector in R&D investment, collaboration and technology transference is hindered in Spain by the composition of the producers of deep tech, as they are mostly constituted by SMEs with low technology intensity. These SMEs have notably reduced their innovation activity (according to the survey of innovation within companies conducted by the National Institute of Statistics, between 2010 and 2018, the number of innovative companies dropped by 29%). Given the important weight of SMEs in the Spanish economy, the contribution of private R&D to total research in terms of percentage of GDP has been approximately 0.7% or only half the EU average over the last decade (BBVA, 2021) and approximately 2 points lower than investment by companies in countries such as Sweden, Denmark, Finland and Germany (CRUE, 2019).

Demand: In addition, market demand is weak for products developed by deep-tech startups and for the science and technology developed by Spanish universities and research centers. Companies prefer to access other companies as sources of R&D and scientific knowledge (The Collider, 2019). In addition, the Spanish industrial sector faces important challenges, including its preoccupying and continuing contraction in the economy (approximately 14,5% of GDP, below the EU objective of 20% for 2020), decreases to contributions from manufacturing[9], the low level of advanced technology and innovation (OECD, 2021), the smaller size of Spanish industrial companies, the reduction in the turnover level over the past decades (11,7% in 2020), and the destruction of many companies during the 2008 and COVID-19 crises (Fariñas, Martín and Velázquez, 2015; CCOO Industria, 2017; Arce, 2021).

In terms of indicators for innovation results, PCT patent applications are inferior to EU levels (43,3% relative to the EU). In 2016, Spain filed 1,343 different patent families (which gives an idea of the diversity and density of research in a country), ranking only 19th among OECD countries[10]. In addition, the country ranks below EU levels in all innovation profiles, with the exception of "noninnovators with potential to innovate" (European Commission, 2021). In fact, Spanish companies, especially the preponderant SMEs, continue to consider innovation a low priority, with "other priorities" cited as the top reason for not innovating, ahead of costs or uncertainty associated with returns on investment in innovation (INE, 2018).

In terms of general **E-Cap**, according to the Global Entrepreneurship Monitor (GEM Spain, 2021), Spain received ratings below 5 (out of 10 points) in all contextual necessary conditions for entrepreneurship,

[6] The PISA 2018 survey showed a substantial decline in Spain's performance in science subjects and, despite strong regional disparities, the country appears below the OECD average.
[7] Eurostat, (2019), *Graduates in tertiary education, in Science, Math, Computing, Manufacturing, Construction*.
[8] OCDE, (2021), *Improving knowledge transfer and collaboration between science and business in Spain*.
[9] https://planderecuperacion.gob.es/politicas-y-componentes/componente-12-politica-industrial-espana-2030
[10] OCDE, (2021), *IP Statistics*.

with the exceptions of 1) access to commercial, professional, physical, and service infrastructures, 2) postsecondary entrepreneurial education, and 3) governmental programs. In particular, entrepreneurial education and training in schools rate especially low (2,18), and public bureaucracy and taxes do not rate well either (3,88). Moreover, the GEM Report (2021) shows that "fear of failure" is a barrier for entrepreneurship, with Spain ranking 14 points higher than the US and 20 points higher than the EU-28 mean. However, it is important to keep in mind that GEM ratings are applicable to all kinds of entrepreneurship and not specifically the creation of "deep-tech" ventures, and hence, it is necessary to look closer at the specific capacities and conditions that enable deep tech.

Regarding E-Cap data that are especially relevant for deep tech, it is important to highlight that a euro invested in scientific startups in Spain translates into a turnover of only 30.000 euros, an amount that is 9 times higher in the EU-28 and 225 times higher in the US (The Collider, 2019). Furthermore, although the percentage of new enterprises in 2021 was above the EU (European Commission, 2021), in 2020, 90,2% of new entrepreneurial initiatives in Spain were for a low technology level (GEM Spain, 2021). In addition to the distressingly low proportion of high-tech initiatives and its consequences for competitiveness, in Spain, entrepreneurial initiatives that tackle important societal challenges, or "mission-driven" initiatives (e.g., climate change, health, food security, clean energy), have decreased over the past years (GEM Spain, 2021).

Funding: In terms of funding for deep-tech entrepreneurship, the Spanish venture capital (VC) industry is flourishing (Hafied, 2022). The cumulative valuation of Spanish startups has quadrupled since 2015, reaching up to 46 billion euros in 2021 (ASCRI/DealRoom, 2021), and in 2020, Spanish VC reached an investment record, with a total volume of 833 million euros (ASCRI, 2020). However, Spanish VC investment is very concentrated in early-stage funding (Hafied, 2022) and remains smaller than in other European countries (e.g., 5.4 billion euros in France and 5.2 billion euros in Germany in the same year) (EY, 2021). In addition, the smaller relative size of Spanish VC firms is also reflected in deep-tech investments. In 2020, Spain ranked only 10th in Europe in terms of total amounts invested in deep tech for the period 2015-2020, with 700 million euros, representing only 15% of total domestic VC investments[11]. In other words, Spain has fewer VC projects specializing in deep tech with less funds and smaller tickets[12].

Regarding the number of deep-tech ventures in Spain, overall data are lacking but some recent initiatives have tried to map the deep-tech sector as circumscribed to some regions, such as the region of the Madrid Community (Madri+d, 2021) or the city of Barcelona (DEEP Ecosystems, 2021). Based on the data from Startup Radar Madri+d, which draws from the global data platform Dealroom, Langeber (2021) has identified 104 deep-tech companies[13] located or founded in the Madrid Community among more than 400 technology-based companies and classified them into three types of technologies and their combinations: biotech (24%), software (19,2%) and hardware (30,8%). Nine out of 10 of these deep-tech companies are SMEs (41%) or micro-SMEs (49%), and 70% of the ventures were created between 2011 and 2020 (Langeber, 2021).

Additionally, based on Dealroom data, the Startup Heatmap Europe Report 2021 positions Barcelona, with a higher share of deep-tech startups (13,2%), before other cities such as Paris (9,3%), Berlin (9%) and London (7,5%); 296 out of 2248 startups are considered deep tech (DEEP Ecosystems, 2021). However, in absolute numbers, these 296 deep-tech startups are very far below the 1803 found in

[11] The European countries investing the most in deep tech in absolute terms over the period 2015-2020 were the UK (12.6B euros), Germany (5.4B euros) and France (5B euros). Some countries manage to allocate a much more substantial fraction of VC to deep tech, such as 38% in Norway, 37% in Finland and 32% in Belgium (DealRoom, 2021).
[12] Based on data collected by Hello Tomorrow.
[13] The requisite for the categorization of a startup within deep tech has been that "the company needs to participate in the development of the deep technology in which its product or service is based" (Langeber, 2021).

London or the 762 in Paris (Ibid.). These numbers, however, provide only an incomplete picture of the number of deep-tech startups in Spain and hence, make it difficult to rank the country among other EU countries. Box 1 shows an example of a Spanish deep-tech venture.

Box 1: Example of a Spanish deep-tech venture

Company: Ienai Space (https://ienai.space/)

Industry: Space tech. Industry 4.0 applied to aerospace.

Technologies: advanced manufacturing, nanotechnology, microtechnology, additive manufacturing, hardware defined by software, customizable propulsion systems…

Description: Working toward MANEUVERING AS-A-SERVICE, an end-to-end business model for streamlining propulsive phases in satellites under 300 kg. At ienai SPACE we work on in-space propulsion solutions: we manufacture and operate the small, embedded rockets that maneuver satellites around once they are already in orbit. As you may know, this is a critical task in most missions and it is becoming ever more critical as more and more satellites are launched every year and issues like space debris and collision avoidance become commonplace. We have developed a proprietary electric propulsion technology focused on very high efficiencies (the most important parameter nobody talks about in this tech space), linked with a unique software approach to customize and eventually operate these thrusters.

Products:

Athena (Adaptable thruster based on electrospray for nanosatellites): Introducing the world's first fully customizable on-board electric propulsion system. Based on electrospray technology, Ienai's thrusters can be tailored to the requirements and constraints of any mission and platform. The end product is uniquely engineered to meet the challenges of pushing your spacecraft further, for longer.

Ienai GO: The world's first rocket-design-as-a-service. From 2U to 27U or custom platforms, from RAAN spacing to orbit changes or drag compensation. Build your custom rocket to deliver the maximum performance for your unique mission and platform.

Source: Ienai Space

3.2. Stakeholders' perceptions about system inputs for I-Cap and E-Cap in deep tech

3.2.1 Human capital

The interviewed stakeholders highlighted some of the weaknesses of the human capital driver of I-Cap and E-Cap in deep tech, particularly addressing the low applicability of higher education skills. Higher education, although high quality in theoretical training, lacks a practical focus on solving real-world problems and shows many limitations in terms of innovation and entrepreneurship (I&E) training. They also highlighted that this low practical focus is found not only in the academic arena or in university training but also in the scientific arena, as researchers do not generally pay enough attention to the practical applications of scientific results. This problem results in a low level of engagement in entrepreneurship, which is reinforced by the few facilities that exist for the spread of academics and researchers to the business arena.

In addition, interviewed entrepreneurs highlighted that the personnel working in the technology transfer offices of universities and research centers often lack the necessary experience in terms of the needs of entrepreneurs or knowledge about the specifics of I&E in deep tech, and hence, this weakness in the human capital driver poses additional barriers to motivated entrepreneurs. Table 2 illustrates weaknesses in the human capital driver highlighted by the stakeholders, with relevant quotes from the interviews.

Table 2: Main weaknesses of the human capital driver

Weaknesses	Relevant quotes from the interviews
Academic arena	
Low focus on practical applications of education	"There (working in industry), I realized the distance between the academic world and applying a technology to solve a real problem. During the degree you learn many things, but there is a need to apply them to something specific. You end up with your degree without having interacted with advanced technologies" (#4).
Shortages of I&E training	"In Spain, they don't prepare us for this (entrepreneurship). During the Engineering degree, they prepare us for \`jack, horse and king\`, they train us so that we end up in the four typical companies that have direct access to students…they prepare us to be \`the engineer\`, not part of the business" (#5).
Low engagement in entrepreneurship	"We have a highly conservative culture and fear of trying new things. I think this is also related to the high risks associated with failure in terms of social personal costs, because in Spain we don't have a sufficient entrepreneurial mass or ecosystem that can reabsorb entrepreneurs that fail in their venture" (#1).
Scientific arena	
Little focus on the applicability of scientific results/knowledge	"The problem in universities and research labs often is that they become a repository of patents, of 'curricular patents' that are produced for the professional development of the researchers, with no intention of exploitation" (#A).
Lack of I&E knowledge	"There is a challenge in terms of people and their training, as many researchers don't have a clue about entrepreneurship, and there is a problem in terms of sensitiveness and ego, and often there is no understanding of what technological entrepreneurship means…important researchers think they will be good at creating a business" (#E)
Low engagement in entrepreneurship and knowledge transfer	"The scientific founders of the startup never truly left research and only got involved with the startup while trying to access a scientific position (…) the engagement with the venture was never a priority for them…public scientific research was, and not the need to face stressful situations, provide results, explain to investors…" (#8).
Mobility across different arenas	
Low mobility of academics	"There are no facilities to get partially involved in a project, e.g., through joint contracts at a research institution and a company. These formats do not exist" (#10).

Human capital supporting technology transfer	
Lack of professionalization of TTOs[14]	"In many universities there are nonexistent or immature TTOs…they lack experience in what it is to be an entrepreneur, in the specifics of innovation and in the specifics of the transference of technology (…) There is a need for professionalization of the TTOs and of the professionals working there" (#2)

Source: Own elaboration.

3.2.2 Funding

Because of the unique challenges deep-tech startups face, these are especially capital-intensive, and funding is a particularly critical challenge that interviews repeatedly highlighted.

Regarding available options for funding deep-tech entrepreneurship in Spain, interviewees mentioned the importance of both public and private initiatives and institutions, (e.g., national funds such as CDTI and ENISA or local ones, such as Sodena in Navarra, and private funds such as Wayra from Telefónica, BizLab from Airbus, and La Caixa Impulse/Validate/Consolidate). Philanthropy (e.g., "Mind the gap" from Fundación Botín) is a third important and lacking source of funds. Some deep-tech venture builders also provide financing (e.g., The Collider), and there are also some coinvestment funds available, which are directed toward research and product development in specific fields of interest[15]. Specialized investors and venture capitalists (e.g., Beable, Bullnet, GoHub) also play a key role. However, interviewees emphasized that the available offer of this key input for I-Cap and E-Cap in deep tech is affected by some important weaknesses, which are summarized in Table 3.

From the **private investment** perspective, interviewees confirm that deep tech is hindered by the current investment model[16] and that existing gaps in the investment funnel are intensified in the Spanish ecosystem compared with that in neighboring EU countries. They highlight that in Spain, we find a) fewer deep-tech specialized VC firms with smaller funds and smaller tickets (#3), b) a tendency to invest little capital with no risk (#A), c) a lack of seed capital and a lack of financing for concept development and early-stage technology development ("valley of death"), which is aggravated by d) the lack of financing for growth and scaling up phases (#A). As a consequence of these weaknesses, many initiatives die in the initial phases (#2), and the startups that survive and are trying to access second rounds of financing often try to reach the US market, instead (#A). Moreover, the role of the Spanish industry as a funding resource for deep-tech entrepreneurship is weak, as there is little interest in science and technology and investment in R&D and innovation is low (#G). As explained before, these investment decisions are also affected by the existing confusion regarding the precise definition of the concept of deep tech (#F).

From the **public funding** perspective, interviewees perceive an inadequate structure for programs and grants and a lack of specific orientation toward deep tech in general public investments (#5). At the national level, some public financial instruments to support deep tech are positively rated, especially those provided by the Center for Industrial Technological Development (Spanish acronym: CDTI) and specifically Neotec and Innvierte (see subsection 3.4 devoted to policy instruments).

However, entrepreneurs perceive that other grants and initiatives are designed in ways that sometimes hinder deep-tech entrepreneurial initiatives, a problem that they relate to the lack of adequate

[14] Technology Transference Offices (TTOs or Spanish acronym: OTRI).
[15] For example, FIK Research, located in the Technology Park of San Sebastian, gathers stakeholders from private companies, financial institutions, local and regional governmental institutions and health institutions and focuses on developing products to improve the quality of life of elderly and disabled people.
[16] Current VC funds are structurally unfit to invest in deep tech, in terms of lifetime, size, and incentives, and rely on the power of distributed investments and risk-adjusted investment (Portincaso, Gourévitch, De La Tour, Legris and Hammoud, 2021).

understanding of deep tech and its implications for specific needs and support programs. For example, interviewees emphasize that some grants require *a priori* information and indicators about the steps that are going to be followed, although in deep tech, these are difficult to guess. As a consequence, what is described is often perceived as “nothing new” and hence, grants are provided around “ethereal technologies” (#8). In addition, interviewees specifically mentioned the detrimental effects of delays in payments from some public grants on the survival of these types of ventures. The situation is compounded by an insufficient public investment in deep-tech entrepreneurship, and weak support for helping the move from grant to venture funding and scaling up. Some interviewees emphasize that some public universities and scientific and technological institutions (STIs) not only lack the resources for technology transfer but sometimes also interfere with access to other sources of funding due to bureaucratic limitations (#2).

Because of the mentioned weaknesses and the smaller size of funds in Spain, **coinvestment** between different types of funding institutions and between public and private organizations becomes essential. In this sense, interviewees emphasized that, although there are some interesting programs, there does not yet exist a critical mass of coinvestment initiatives (#F) and that, hence, more of these instruments are needed.

Finally, and in addition to the mentioned improvement areas, three important remarks have been highlighted by interviewees. First, it is important to consider that sometimes, requirements that public institutions completely expend the yearly budget create time restraints that limit the efficiency of the applied support instruments (#H). Second, investment offers are not the only area for improvement; rather, Spanish entrepreneurs also show weaknesses, which include low competencies, a lack of ambition and experience in accessing high amounts of funding (e.g., national and European public programs), a short-term mindset, and lack of knowledge about funding sources (#1). Third, there is a need in Spain to reform the prevalent investment model, which is inadequate for promoting innovation in practice. In this sense, experts highlight that although the message is usually directed toward creating employment and impact, investment in Spain is still speculative, focused on exit strategies rather than in continued investment in the companies, and aimed at startups that spend a high proportion of those investments in marketing and gaining clients (#B), rather than in industrialization and technology development.

Table 3: Main weaknesses of the funding drivers

Weaknesses	Relevant quotes from the interviews
Private investment arena	
General frictions of the investment model intensified	“Abroad we would have been able to access more investment for the same equity” (#3). “In Spain, venture capital acts as if they were banks” (#5).
Lack of expertise in deep tech	“In other countries investors and banks have more knowledge, experience and maturity in the field: A higher volume of exits means higher reinvestment in the ecosystem, better mentality and more closeness between research and market” (#D).
Low industry investment	“The Spanish industry is not aware of the importance of using science. Only 5,5% of the industry hires R&D from universities. Instead of local developments, they hire expertise abroad, from competitors” (#G).

Public investment arena	
Inadequate structure of some funding and grants	"With public funds you often need to develop the whole project before getting the money. In Europe they advance 80-100% of the funds, but in Spain the problems get worse when you develop the project and still don't get the money in 2-3 years. Sometimes they don't pay and wait for the project to die" (#5). "If we are talking about public money, we enter the arena of public grants and we are screwed. I would say good things about CDTI in general and about the Neotec format specifically and about 'Torres Quevedo'…but other grants are wrong" (#8). "Calls for European projects usually have too scientific a focus when assessing entrepreneurial projects. At the end, what companies present is far from their capabilities as they try to become more scientific. This makes assessment difficult" (#10).
No deep-tech entrepreneurship orientation	"The public sector invests in projects, but not in deep tech even when it creates value; there are difficulties accessing funding" (#5). "Funds for the early stage are very limited…and the focus is still on SMEs and big companies, not in startups" (#9).
Public STI often acts as interference for funding	Bureaucracy at the University represented a barrier to private funds "as the Provost refused to sign off on a process, as required" (#9) or "because of delays in university industry technology transference (UITT)" (#2).
Coinvestment	
Weak coinvestment	"When creating a fund, private investors do not understand deep tech and are difficult to convince. Hence, we depend on the leverage of public money (…) we miss coinvestment institutions with capabilities for supporting advanced phases" (#F).

Source: Own elaboration.

3.2.3 Infrastructure

Infrastructure for I&E is a broad concept that goes beyond physical infrastructure and access to specialized technical equipment and hence, also relates to available services, including the regulatory infrastructure, planning and space policies, and digital policies. In this sense, and as already stressed, interviewees have emphasized that Spain lacks a specifically deep-tech-oriented infrastructure and strategy, starting from the necessary delimitation of the concept and its precise definition (#H).

In addition to this important starting point, interviewees emphasized the high complexity (e.g., in bureaucratic red tape and fragmentation) and low transparency of infrastructure for the support of R&D, of technology transference and of deep-tech entrepreneurship. In addition, entrepreneurs highlighted significant regional imbalances in terms of available support (#C), which, in many cases, forced deep-tech entrepreneurs to change their location to more "entrepreneurship friendly" regions (#1). The lack of adequate and proactive TTOs for the support of technology transference, among other infrastructural weaknesses, has also been emphasized by different stakeholders.

Table 4 summarizes the weaknesses of infrastructure as a driver of the deep-tech economy as emphasized by the interviewed stakeholders.

Table 4: Main weaknesses of the infrastructure driver

Weaknesses	Relevant quotes from the interviews
Lack of specifically deep-tech-oriented entrepreneurial infrastructure and strategy	See Table 3 for the description of the funding infrastructure. "In Spain the public infrastructure is investing in projects, but not in deep-tech projects that create prosperity and in projects that need a lot of investment but not for marketing and publicity but to advance in their TRL" (#5)
Low transparency and high complexity of available services and instruments	"Even within the polytechnic university, where the European Space Agency was located, there was no knowledge or information about existing programs…The agency had a program for ideas within the campus, but there was no publicity about it…we had to look for it proactively" (…) "Nobody tells you where to go for funding" (#5) "The university has incentives for TT, but these are not transparent… even reaching the TTO is not that simple" (#7) "Many entrepreneurs in Spain lack the knowledge about where to go to access funding" (#1)
Regional imbalances and fragmentation	"There are important differences between 'core' universities and 'periphery' universities and most programs are centered in Madrid…some universities always appear in rankings or participate in European research projects…this will create a reinforcing negative cycle in which the gap in terms of competitiveness will get bigger" (#C)
Lack of adequate infrastructure for TTOs	"In many universities there are nonexisting or immature offices for the transference of research outcomes (…) In our case, it was us who created the templates for technology transfer that the OTRI uses nowadays…because nothing existed before." (#2)

Source: Own elaboration.

3.2.4 Market demand

Regarding the role of market demand as input for I-Cap and E-Cap, interviewees have focused on the problems in the **industrial sector** (i.e., low investment in R&D, less advanced high tech, and decreasing value added in industry and manufacturing) that complicate the situation for deep-tech entrepreneurship. Deep-tech startups are particularly challenged, as the lack of industrial demand in Spain makes it more difficult to access clients and providers in some sectors or even to profit from the economies of proximity for getting to the break-even (#8). In addition, interviewed experts stated that Spanish industry is short-sighted (#A) and unaware of the important role that science plays and hence, has little collaboration with Spanish scientific institutions (#G), buying most R&D from other companies and abroad (The Collider, 2019).

In addition to industry demand, market demand for deep-tech startups can be substantially activated by **policy levers** such as public sector procurement, prizes, and grants, which can drive innovation toward specific national objectives and missions (Budden and Murray, 2018). In this sense, interviewees emphasized weaknesses in the current design of some public grants. Specifically, interviewees mentioned that the lack of a national policy to explicitly support deep-tech ventures is reflected in the emergence of programs that support entrepreneurship in general, without making any distinction between copy-cut initiatives (e.g., Cabify as a copy of Uber) or ventures that use technology but cannot be considered deep tech (#5) or impact-driven.

Moreover, policy experts have highlighted the need for specific instruments within public administrations to efficiently channel available funds to impact-creating ventures, as the absence of these instruments has thus far restricted the maneuverability of supporting institutions and imposed important restrictions on public procurement (#H).

Table 5 summarizes the weaknesses of the market demand driver as emphasized by the interviewed stakeholders.

Table 5: Main weaknesses of the market demand driver

Weaknesses	Relevant quotes from the interviews
Industrial fabric	
Short-sightedness of the industry	"There is a lack of long-term vision and strategy in the Spanish industrial sector; they are thinking about their core business now, instead of thinking about their core business in the changing future. This is a real problem" (#A).
Weak industrial sector (deindustrialization, small-sized, medium-low tech)	"In Spain we do not have industry…the factories that we have were created long ago, and there is always R&D behind a factory…that's what we lack. Let's stop talking about science and R&D and start talking about industrialization… Since we don't have industry, any spinoff is alone in Spain" (#8).
Government	
No specific deep-tech public demand	"The public sector invests in projects, but not in deep tech that creates value and that has difficulties accessing funding" (#5). "When we talk about venture building in Spain, we talk about initiatives that create copy-cut ventures" (#E).

Source: Own elaboration

3.2.5 Incentives and culture

Regarding the fifth driver of I-Cap and E-Cap, Spain does not have a culture that celebrates innovation and deep-tech entrepreneurship. Rather, interviewees mentioned a highly conservative culture, with a powerful fear of trying new things, high risks of failure in terms of social personal costs, and a philosophy in which success is based on individual effort and not on a strong supporting system (#1 and #2). This conservative cultural tendency is reflected not only in the activity of entrepreneurs but also limits the commitment of other stakeholders. In fact, it inhibits the involvement of private actors and corporations in scientific collaborations and in deep-tech innovation. Both government actors and venture capital firms in Spain "*behave as if they were banks...avoiding the risky part*" (#5).

In addition, interviewees highlighted some of the implications of Spanish scientific culture for the promotion of deep-tech entrepreneurship and collaboration with other stakeholders. First, the "public domain" mentality of universities and the "open science" philosophy of most researchers discourages entrepreneurial attitudes. As a result, for many researchers, moving from science to business is perceived as a "failure", or even seems "capitalistic" (#10) or to be "going to the dark side" (#2 and #6); hence, impact-driven entrepreneurship does not appear to be an appealing alternative path to scientific research.

Second, perhaps as a consequence of the perception that basic science and research are divided from real impact and entrepreneurship, interviewees stress attitudes in the scientific arena that hinder R&D collaboration and technology transference. In particular, entrepreneurs mention the emergence of a) defensive attitudes among researchers, specifically regarding accountability for their work and the use of public money (#8) and seemingly aggressive negotiations over intellectual property rights (IPR) for their patents and inventions (#3). This situation is linked to b) unrealistic perceptions about the applicability and value of created knowledge (#3 and #11). Some interviewees are specifically critical of the approach to collaboration and IPR negotiations performed by the main Spanish public research institution, i.e., CSIC. Although they recognize that this institution has outstanding researchers, the entrepreneurs consider them to be "too obsessed" about IP and about licensing technologies, believing that the patents they have "in their freezer" are very valuable *per se* (#8) and can be exploited directly without further codevelopment with the company, which is usually not the case (#3). As a result, they state that some researchers and research centers "*believe that they are doing a favor to the company by collaborating"* (#8).

Third, although it seems clear that successful deep-tech entrepreneurship requires collaboration and cocreation among different stakeholders in the ecosystem, some interviewees emphasize that agents, especially those in academia, can be afraid of giving up control over developed initiatives, even when this would be necessary to increase the probability of success of a venture (#11).

These perceptions about the scientific culture of other stakeholders, particularly in corporations, hinder communication and collaboration. In fact, this "clash of cultures" and the lack of understanding among the different academic, corporate, and scientific norms and environments was very often mentioned by interviewees as an important barrier to deep tech. In other words, interviewees state that each sphere speaks a "different language" and defends different interests, which makes negotiations difficult (#D, #E, #F), as mutual understanding is essential for successful collaboration and cocreation.

These cultural problems are reinforced by the organizational and institutional barriers described in the previous sections (e.g., excessive bureaucracy, insufficient support by TTOs), which create disincentives for entrepreneurship and collaboration between stakeholders. In addition to these disincentivizing barriers, interviewees state that existing incentives for researchers to become entrepreneurs in Spain are weak compared to other countries, for example, in terms of the equity of the start-ups that scientific founders are allowed to have (#11, #G).

Finally, interviewees also highlighted areas for improvement in the regulatory infrastructure, which is not yet adapted to the reality of deep tech. Specifically, the following regulatory areas have been emphasized: a) accountancy rules (#8), b) incompatibility legislation for public researchers (#10), and c) excessive regulatory bureaucracy (#5), particularly in universities and research institutions (#6).

Table 6 summarizes important weaknesses affecting the driver of culture and incentives in I-Cap and E-Cap for deep-tech ventures.

Table 6: Main weaknesses of the incentive or culture driver

Weaknesses	Relevant quotes from the interviews
Spanish culture	
Conservative culture: - Fear of trying new things - High risk of failure	"Even though this cultural problem is changing little by little, in Spain, people are not allowed to fail more than once and even less 'encouraged' to fail often as a way of learning" (#A). "Spain has a highly conservative culture and a culture of public service and having a 'life's work' in which there is fear of trying new things, which relates to the high risks of failure and its penalty" (#2).
Academic/Scientific culture	
"Public domain mentality" and scientific culture that creates attitudes that hinder R&D collaboration and technology transference: - Negative perceptions about entrepreneurship - Defensive attitudes (regarding accountability for research and IPR negotiations) - "Disconnected" and "unrealistic" scientific culture - Resistance to giving up control	"Researchers want to receive public money to research their 'bacteria' but without being asked for anything in return. This is the only sector in which this happens…it's a mistake (…) We had research contracts with CSIC, but it produced no results, it did not even have the possibility of requiring results, and there was no compromise among researchers. It is terrible: we are paying a contract in order to research 'x' and CSIC makes it compulsory that the results are theirs…and then we need to negotiate whether they give something to the company (…) Thinking that development is just manufacturing what you wrote down in a scientific paper or a patent is wrong. It is important to think about it as product development and to check whether the market wants what you have created" (#8). "There always needs to be codevelopment. The idea that the technology comes from the research centers and then companies exploit it is wrong" (#3). "Everyone feels that they have contributed more than they have (…) we magnified the fact that we had achieved a TRL[17] 6 and underestimated TRL 7 to 9. There were phases we didn't know about. We were into R&D and we didn't care whether what we designed was manufacturable or not…and in fact it wasn't (…) In Spain, we like to do things on our own as much as possible and we have limitations to cooperation and cocreation, which imply that you will assume risks. But this is implanted in the university ecosystem, because once a university has developed something, it does not want to give away that property in order to increase its possibilities of success. We need to lose the fear of giving away control. If you want to keep people from different spheres motivated (e.g., financial, commercial…), you need to diversify control and not keep it all for yourself" (#11).

[17] Technology readiness level (TRL) is a method for estimating the maturity of technologies, which uniformly establishes and defines nine different phases of technological development: from basic research (TRL 1: basic principles observed and TRL 2: technology concept formulated) and applied research (TRL 3: experimental proof of concept, and TRL 4: technology validated in lab) to experimental development (TRL 5: technology validated in relevant environment, TRL 6: technology demonstrated in relevant environment, TRL 7: system prototype demonstration in operational environment, and TRL 8: system complete and qualified) and commercialization (TRL 9: actual system proven in operational environment).

Few incentives for researchers to become entrepreneurs and low visibility of alternative paths	"I know of cases in Germany, France or UK in which the principal researcher has left the university in order to create the startup and has received institutional support and facilities, such as, for example, a 30% stake in the company. In Spain these incentives are very few" (#11). "We need to rethink the way we reward. Why should a scientist that wants to become an entrepreneur get only a 10% stake of the company? In the Canadian model, they think about business in the long run" (#G).
Regulatory framework not adapted to deep tech: e.g., - Accountancy rules - Incompatibility rules Excessive regulatory bureaucracy	"We cannot list our R&D among our assets because our auditors are used to assessing shoe shops and not deep tech (…) here investment and capitalization are frowned upon" (#8). "Contractual formats that allow for partial work in private companies and in research do not exist (…) mainly because of incompatibilities built into the public research centers" (#10). "In a year's time, we had to go through three fiscal inspections; one of them was for the VAT devolution, which is normal for a company that only spends because it is in the R&D development phase. For a company of ten employees (…) everyday work is already difficult, but if they (regulatory powers) make it even more difficult (…), even the stupidest things, such as "signing hours" for flexibility (is a burden). These types of things that you continuously need to do make it difficult to be an entrepreneur" (#5). "Administrative inflexibility and bureaucracy are a huge barrier…. Even though there is a movement to change this situation, it takes time" (jokingly scores it as 12 out of 10 as a barrier in the Likert scale) (#6)

Source: Own elaboration.

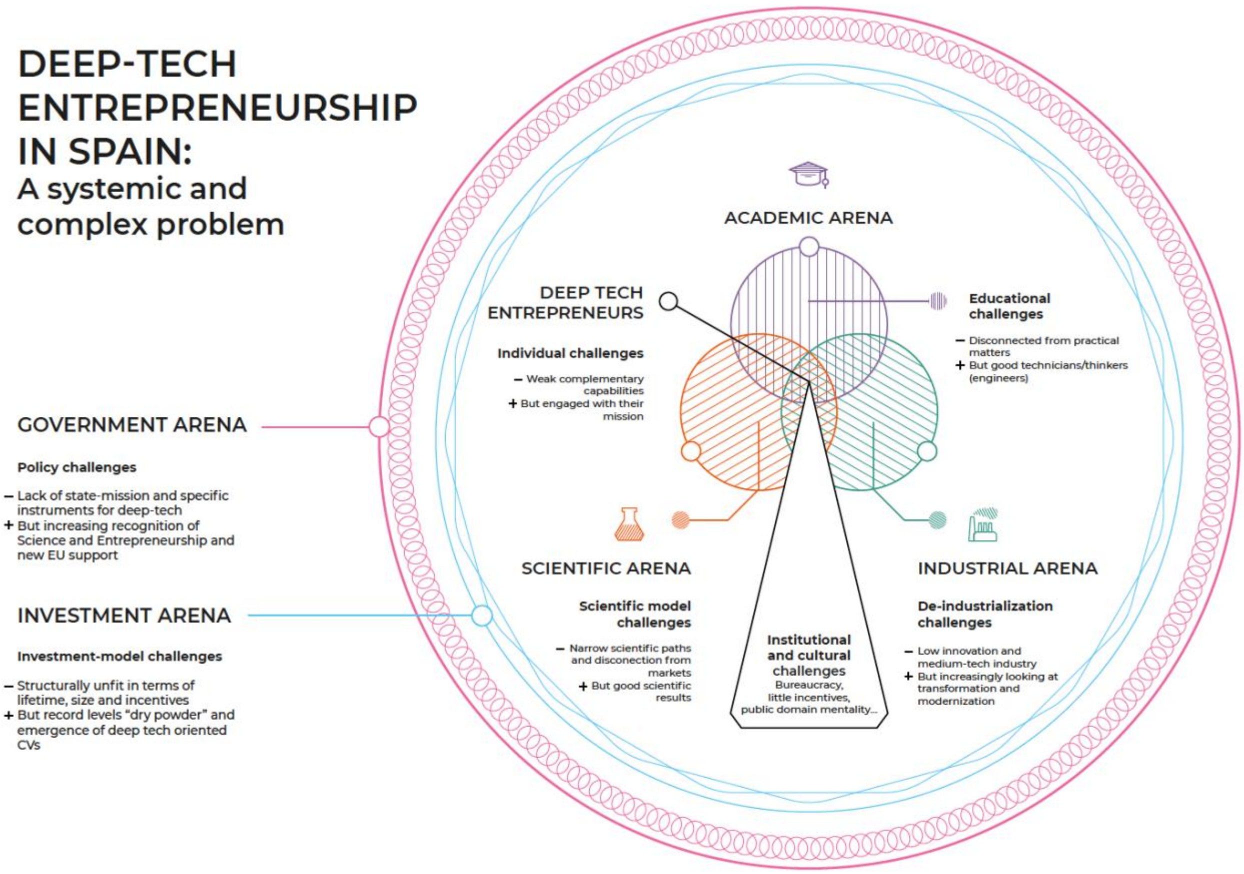
3.3. Strengths and weaknesses: A systemic and complex problem

The analysis of the interviews and of the selected literature allows us to draft a picture of the current strengths and weaknesses of the Spanish deep-tech ecosystem. As a result, Figure 1 presents a map of the systemic and complex problem we aim to understand, classifying the weaknesses and strengths into different action spheres that are related to the five stakeholders of the innovation and entrepreneurship ecosystem (Budden and Murray, 2019): 1) universities, or the academic and scientific arena; 2) corporations, or the industrial arena; 3) government; 4) venture capital, or the investment arena; and 5) entrepreneurs. Deep-tech ventures may emerge from different combinations of these spheres, but in particular from the area between academia/research and industry.

Regarding the strengths of the ecosystem, Spain has a good substratum of human capital for deep tech, as it leads in number of PhDs (European Commission, 2021) and is recognized as a producer of good technicians and theoretically well-trained engineers (#5). In addition, it is also recognized for the high quality of its research and scientific results (#2), and the country shows good performance at the European level; in particular, it ranked third in terms of participation and first in terms of project leadership in the recently finalized Horizon 2020 EU program (García, 2021).

Moreover, Spain is considered a leader in areas such as the establishment of information and communication technology (ICT) infrastructures, intelligent mobility, mobile connectivity and payment platforms (García, 2021). In addition, the report “España a ciencia cierta” (Fundación Rafael del Pino, 2021) offers a prospective exercise that analyzes the availability of specialized knowledge in ten scientific areas related to promising transformative technologies in which it would be strategic to become internationally positioned: telemedicine, hydrogen, photonics, neuroscience, mathematics, rapid tests, agriculture, augmented reality, supercomputing, and nanomedicine (García, 2021).

Figure 1: A systemic and complex problem



Source: Own elaboration.

Finally, although it cannot be considered a strength, it is good news that Spanish society has progressively become conscious of the relevance of science and innovation since the COVID-19 pandemic (Guimón, 2021). Similarly, it cannot be considered a strength *per se* but an advantage that the country is part of the EU, and hence, Spain will be importantly assisted in its postpandemic recovery with funds that will be partially applied to innovation (ibid).

However, the weaknesses of the Spanish innovation ecosystem are preponderant, and many experts consider the country to be “stagnant in mediocrity” (Guimón, 2021) and “living apart from the technological revolution”, with a strong and preoccupying propensity to buy external technology (García, 2021). Moreover, some existing strengths are actually, paradoxically, a challenge, as even good scientific results have little effective commercial value or practical application (#G). Consequently, Spain has few examples of technology transfer (OECD, 2021) and a weak showing in turnover among scientific startups (The Collider, 2019).

As explained by the *MIT iEcosystem framework* (Appendix 1), the weaknesses and/or barriers to I-Cap and E-Cap and their interactions impact the entrepreneurial outcomes of Spain. The important symptoms arise in terms of a) **a low technology level** in the initiatives and low technology transference (e.g., a high number of patents with no market application), b) **low value/impact,** and c) **little scalability** of the initiatives, with few links to industry and minimal investment scale (GEM Spain, 2021).

We have classified the weaknesses and paradoxes that affect all five stakeholders of the innovation ecosystem (Figure 1) into the five input categories or drivers that need to be defined and optimized for I-Cap and E-Cap (i.e., human capital, funding, infrastructure, demand and incentives or culture).

a) Human capital: An insufficient supply of people "fit" for deep tech, concentrated in some regions

Spain has a high level of scientific production and the available population with tertiary education and doctorate degrees is above the European average, but at the same time, it has an insufficient supply of people "fit" for deep tech. In fact, being "fit" for deep tech means not only 1) having specific frontier science/technological knowledge but also 2) being a) engaged in transforming that knowledge into solutions to real problems, b) familiar with the language of companies and investors, and c) trained in the practice of innovation and entrepreneurship.

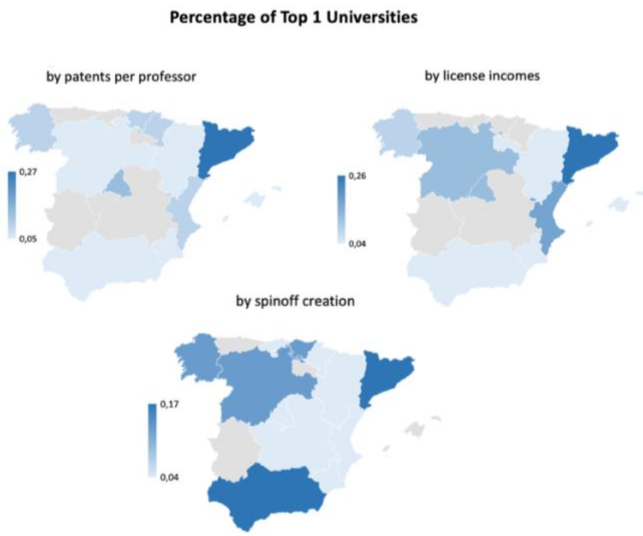
In this sense, Spain shows good results for the first requirement (i.e., specific knowledge), but it is important to remember that the number of students who enroll in STEM degrees, who represent a key source of human capital for deep tech, is strongly decreasing (Cavero and Ruiz, 2017). An additional problem is related to national brain drain, with 12,000 researchers established abroad (García, 2021).

However, regarding the second requirement (i.e., I-Cap and E-Cap related competencies), we find important weaknesses in the education and research arena, especially: a) a strong focus on theoretical concepts that train good technicians and thinkers (e.g., engineers and scientists) at the expense of a practical focus and connection to real problems, and b) a lack of experience among professors[18] and researchers in innovation and entrepreneurship (I&E), which results in c) a low engagement of students in problem-oriented and impact-driven action, such as deep-tech and value-creating entrepreneurship. This low supply in the human capital driver for I-Cap and E-Cap is especially important for deep-tech entrepreneurship, as this type of venture requires the involvement of advanced scientists and/or technicians. Reasons for the low engagement of academics in industry include few incentives, such as the outcomes for which scientists are assessed, paid and promoted. As an interviewee illustrated, "*In Spain, state researchers publish. They care more about the paper than about the creation of value*" (#G).

In addition to the problems of practical disconnect in the education and research system, other important weaknesses affecting this paradox are 1) the low mobility of academics from the university and research arena to industry; 2) the low visibility of alternative paths and role models for scientists; and 3) a "public domain" mentality of universities directed toward an "open science" philosophy, which often clashes with views of knowledge as proprietary and oriented toward achieving competitive advantages (Tables 2 and 6).

[18] Only 18% of university professors with a PhD are involved in technology transfer activities (CRUE, 2019).

Figure 2: Concentration of universities in top ranked position



Source: Own elaboration based on Ranking CYD 2021.

Finally, Spain shows a high level of geographical concentration of “fit” human capital for deep tech in some regions and top performing universities, as evidenced by the differences in technology transference results by different universities (Figure 2). This geographical concentration of outcomes is also related to the fact that 67,3% of students are concentrated in four regions (Fundación CYD, 2020), specifically Madrid (21,8%), Andalusia (18,2%), Cataluña (16,2%) and the community of Valencia (11,1%).

b) Funding: Small amount of available funds and inadequate instruments for deep tech

Spain appears to currently have sufficient available funds, as VC firms reached an investment record (ASCRI, 2020) and public funding has increased with the entrance of Next Generation EU Funds. However, these funds have not yet been sufficiently channeled toward impact-driven deep-tech initiatives, and hence, available funds for deep tech are still too limited. Out of the 22 deep-tech VC firms based in Spain (see Appendix 3 for a relation of deep-tech investors based in Spain), only 5 are exclusively investing in deep tech in Spain, while the rest also invest in other regions (Hellow Tomorrow, 2022).

Important weaknesses affecting this paradox are, among others: a) the lack of understanding of deep tech among private investors (#F) and the frictions, which are intensified in Spain, of the current investment model, i.e., lifetime, size and risk-adjusted investments (Portincaso et al., 2021); b) a lack of understanding of deep tech among public funders, as many grants are not adequately designed for the needs of this type of initiative (Table 3); c) the insufficient critical mass of initiatives for public and private coinvestment; and d) the lack of specific instruments that efficiently channel public funds to these deep-tech ventures and allow for the effective execution of available budgets. In particular, this last problem has been highlighted by public servants (#H) who find important challenges in funneling budgets to support deep-tech projects. In fact, the low execution of public R&D budgets (e.g., 51,3% in 2019) is attributed not only to problems in administrative capabilities of the public sector but also to the failed design of political instruments (Guimón, 2021).

c) Market demand: Weak internal private and public market demand for deep tech

As stated in relation to human capital input, brain drain in Spain is an important problem, as the country invests large amounts of public money in training and educating high-quality engineers and scientists who leave for employment in other countries (García, 2021). In addition to the instability of a research career in Spain, incurred as a consequence of the drop in R&D expenditures during the 2008 crisis (Guimón, 2021), brain drain has also occurred as the size of the industrial sector is reduced in the economy.

This deindustrialization process also means that there is a weak internal market demand for deep tech, making it difficult for startups to access their first clients and providers within the country (#8). In addition to weak private demand, the public sector has also traditionally been inefficient at pushing market demand through direct “demand-pull” policies and through other policies aiming at connecting the research arena with the industrial arena (Guimón, 2021).

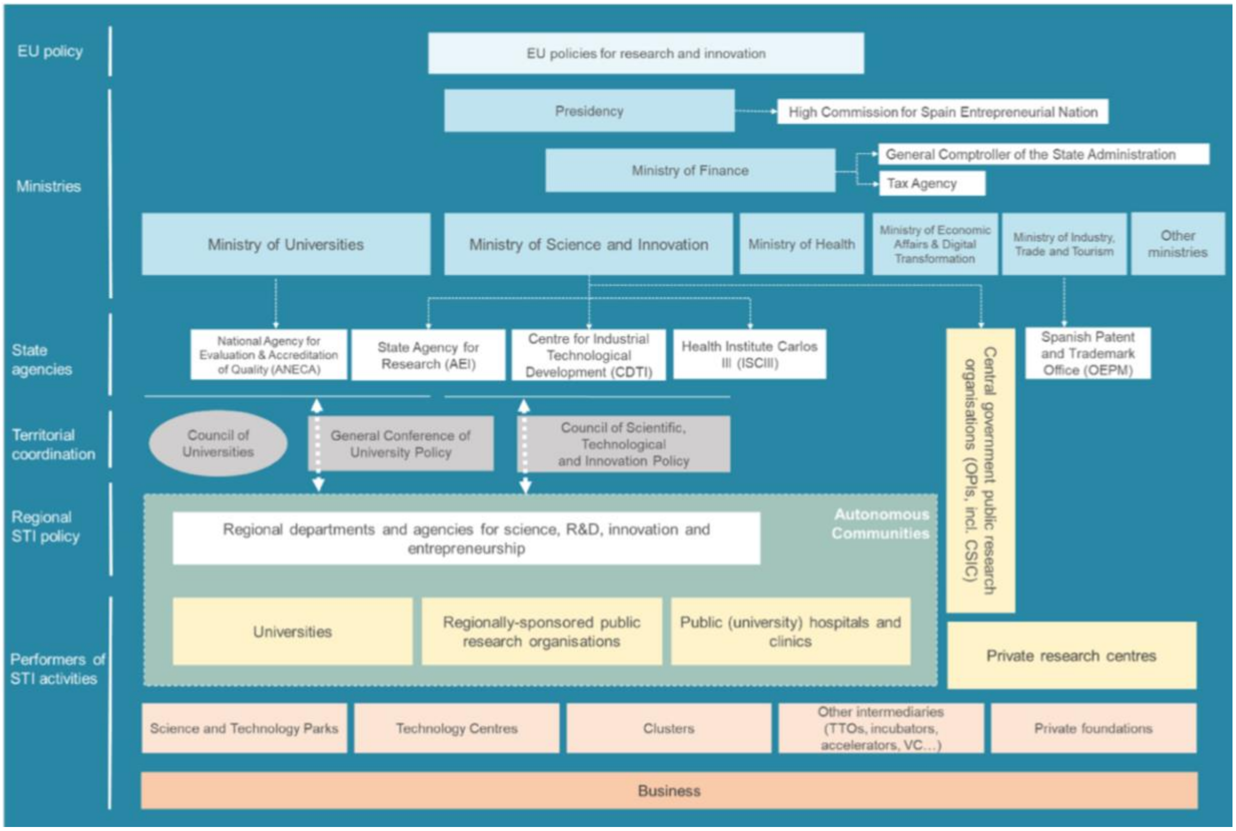
d) Infrastructure: Disarticulation of instruments and policies for deep-tech support and specific barriers and weaknesses affecting support institutions

The blurry definition of the deep-tech concept and its implications for innovation and entrepreneurship in the supporting ecosystem is not the only challenge that Spanish ventures need to face. The structural imbalances of the Spanish science and innovation system, with a high diversity of regional models and high complexity of policy governance (OECD, 2021), create an important disarticulation of the deep tech and entrepreneurial support systems and low transparency for existing alternatives.

As a decentralized country in which power is shared between the state and the regions (*Autonomous Communities*), who are also given a constitutional basis for creating public policies on innovation (Article 148.17 of the Constitution), we find very different situations, depending on local administrative traditions and industrial history (Hafied, 2022; OECD, 2021). As a consequence, the Spanish innovation system is particularly fragmented, with a multitude of actors operating at both the central and regional levels. This fragmentation leads to duplication, increased bureaucracy, and multiple risks of governance conflicts between entities (Ibid.).

The diversity of regional models adds complexity to the infrastructure, as policy governance depends on different governmental levels (Figure 3). For example, while CSIC (i.e., the main Spanish public research institution) is a state agency depending on the Ministry of Science and Innovation, universities and public university hospitals and clinics are dependent on the autonomous communities. Moreover, innovation policies are deployed in very different ways in the different autonomous communities, depending not only on the balance of the local economic structures and modes of administration but also on the different levels of regional development and varied budgetary restrictions. Borrás and Jordana (2016) show that while the old industrial basins are better integrated into international production chains and have developed public innovation policies geared toward businesses, other less developed regions are oriented toward more academic measures.

Figure 3: The policy governance of Spain's science and innovation system, 2021



Source: OECD (2021).

Regarding key research infrastructure in Spain and the availability of specialized technical equipment**,** it is important to bear in mind that most organizations are of a public character[19]. However, as a consequence of the disarticulation and complexity of the ecosystem, the specificities of the different support institutions are many, and the intensity of the barriers and weaknesses affecting them are also heterogeneous (see Appendix 4 for the description of key infrastructures impacting deep tech in Spain). Box 2 describes the main weaknesses affecting key infrastructures relevant for deep tech in Spain.

In the academic/scientific arena, most of the university industry technology transference (UITT) barriers are analyzed in the literature (Siegel et al., 2003), including organizational barriers contingent on each specific institution of origin (e.g., bureaucracy, resources devoted to technology transfer, skills of the TTOs, aggressiveness in exercising intellectual property rights) and other more general barriers.

Box 2: Main specific weaknesses affecting key infrastructure relevant for deep tech

Universities, the main actors in the execution of R&D (OECD, 2021), are dependent on regional science technology and innovation (STI) policies and funding and are criticized for being highly bureaucratic and endogamic. There is a low porosity to knowledge transfer and collaboration with other stakeholders (OECD, 2021) and the funding system is insufficiently based on performance criteria (Hafied, 2022). In addition, the social councils, which should be in charge of catalyzing university

[19] The OECD (2021) diagnostic report offers an overview of the public R&D and innovation support institutions and of the policy instruments implemented in Spain to support science–business knowledge transfer and collaboration.

participation in society, are particularly constrained (OECD, 2021) and hence, university governance is not very open to outsiders. As universities are endowed with a great formal autonomy, the differences between organizations adds institutional complexity to the already high regional and national complexity. For example, each institution applies different interpretations of the regulatory framework for technology-based company (TBC) creation (CRUE, 2017; Trenado and Huergo, 2007) and have different types of TTOs (e.g., in terms of size, professionalization, maturity, and proactivity). Hence, diverse internal norms and procedures are applied across the 80 organizations of the university system (Ministerio de Universidades, 2021), adding institutional complexity to the national complexity (CRUE, 2017).

Public Research Organizations (PROs; Spanish acronym: OPIs) are also heterogeneous as some are linked to the central government, while others are linked to regional administrations. PROs linked to the central government are more bureaucratic and subject to strict rules, while other more recently created organizations have greater flexibility and autonomy and are usually constituted as foundations (OECD, 2021). In addition, more recently created nonuniversity PROs (e.g., CERCA, BERC or IMDEA) have usually established their own procedures to create new spinoffs and have higher flexibility than the centers attached to universities (Ibid).

Technology Centers (TCs) [20] are similarly very heterogeneous in terms of size and activity because of differences in the autonomous regions in which they are based. However, some regions, including Madrid, currently lack TCs. In addition, there is no formal process of coordination of public investment into TCs, which hinders the alignment of their activity with national priorities (OECD, 2021).

Science and Technology Parks (STPs) are also very diverse (e.g., in terms of the typology of companies they incubate and accelerate and in terms of size) and often have close linkages to public universities and research centers of a region (OECD, 2021). Hence, the specific support they provide for deep tech is also very heterogeneous[21].

Adding to these institution-specific weaknesses, the OECD Report (2021) emphasizes that "*the Spanish public sector does not have any implementing organizations explicitly designed to provide R&D infrastructures and support services for companies*". Moreover, and as already stated, multiple analyses indicate that Spain needs to improve its intermediary knowledge mechanisms (OECD, 2021) and in particular, the capabilities of the TTOs in universities and public research centers, as they generally lack necessary financial resources and human capital. According to experts, "*the professionalization of these intermediation services remains one of the major challenges for science–business transfer in Spain*" (OECD, 2021: 24).

e) Culture and incentives: Highly conservative culture and cultural clashes that hinder collaboration and cocreation and disincentives for entrepreneurial behavior in the academic and scientific arena

Finally, even though the culture seems to be changing, Spain does not have a culture that celebrates innovation and deep-tech entrepreneurship. Instead, it is highly conservative, with a strong fear of trying new things, a fear of high risks of failure and an emphasis on individual effort and success (Table 6). This

[20] According to COTEC, 30% of the innovative activity of companies in Spain comes from TCs, non-profit private research organizations that have their own material and human resources necessary to carry out activities aimed both at generating technological knowledge and facilitating its exploitation, either by existing companies or through the generation of new business initiatives. Their success is measured by the competitive improvement of companies and their contribution to the economic development of their environment (Spanish Federation of Innovation and Technology Entities, FEDIT).
[21] For example, the Madrid Science Park, located on the campus of the Autonomous University of Madrid, close to other research infrastructures and centers of CSIC, has recently created specific acceleration initiatives for the support of deep tech (i.e., CaTaPull Madrid).

cultural problem is reinforced by the disincentives created by different institutional and organizational barriers, such as those created by the current scientific and academic model, which is skewed toward scientific publications and in which some "deviations" from the traditional scientific career might even be penalized as "*going to the dark side*" (#2).

In addition, the lack of shared spaces for the different stakeholders makes mutual understanding difficult, as each stakeholder speaks a "different language." Hence, cultural clashes (e.g., overly aggressive IPR negotiations and unrealistic perceptions about technology exploitation) block negotiations, collaboration and cocreation. The "public servant" mentality of most researchers creates a culture that denigrates entrepreneurial attitudes as a view that threatens the value of open science by considering knowledge to be proprietary and oriented toward achieving competitive advantages (Siegel et al. 2003; Bradley, Hayter and Link, 2013). This "open science" philosophy has its pros and cons, but for impact-driven entrepreneurship, the "disconnect" between science and its practical application to solve social problems represents a weakness.

The geographical and institutional rigidities and weaknesses of the regulatory framework are combined with legal barriers that also tend to limit the effectiveness of innovation policies (OECD, 2021). For example, regarding legislation affecting human capital for I-Cap and E-Cap, the requirements of the "*1984 Law of Incompatibilities of Staff in the Service of Public Administration*" limits the participation of public researchers in companies that exploit the knowledge derived from their research. Although the "*2011 Law of Science Technology and Innovation*" establishes some exceptions, the restrictions imposed by the law of incompatibilities negatively impact spinoff creations (Hafied, 2022). In addition to these laws, some policy instruments promoting the recruitment of R&D personnel (e.g., Ramón y Cajal and Juan de la Cierva programs) do not allow the participation of publicly funded researchers in companies (ibid).

3.4. Current policies and initiatives impacting I-Cap and E-Cap in deep tech

3.4.1 Central government policies

The review of the literature, reports, official documents, webpages and support programs has allowed us to draw an image of the current situation of policy instruments affecting the different inputs for I-Cap and E-Cap in deep tech in Spain, completing the image provided by the OECD (2021) for technology transference. Table 7 offers a list of policy instruments impacting I-Cap and E-Cap, although we do not claim it to be exhaustive (e.g., we have not included policy instruments directed toward the promotion of R&D and scientific production). The high complexity of the support infrastructure, the disarticulation of support policies, the multilevel governance of public policies on innovation, and the low transparency on available initiatives, linked to the fragmentation of information, have posed important barriers for this analysis.

Some of the existing public financial instruments have been positively rated (highlighted in green in Table 7), especially the *Neotec* and *Innvierte* programs provided by CDTI. The *Neotec* program is directed exclusively to the creation and consolidation of technology-based companies (TBCs) based on R&D and following a business model based on the development of own technologies. Since 2015, its format has been based on grants (from its creation in 2002 until 2014, it was based on reimbursable investments, conditioned by their generation of cash flows). The *Innvierte* program supports venture capital investments in TBCs or innovative companies, with the intention of improving technology transference results and facilitating the ability of Spanish TBCs to scale up.

Table 7: Policy instruments at the central government level impacting I-Cap and E-Cap in deep tech

Focus	General Objective	Policy instruments at central government level	Institution	Year	ICap/ECap
Promotion of knowledge transfer and collaboration (OECD, 2021)	Grants and loans for collaborative R&D projects	Challenges – collaboration RDI projects	AEI	2014	Funding/ Human Capital
		CIEN Strategic projects	CDTI	2014	
		Cervera R&D transfer projects	CDTI	2019	
		Science and innovation missions	CDTI	2020	
		Funding for projects in strategic areas	AEI	2021	
		Funding for proof of concept projects	AEI	2021	
		Health technology development projects	ISCIII	N/A	
	Support for the mobility and industry engagement of PhDs and postdocs	Torres Quevedo Grants	AEI	2001	Human capital
		Industrial PhDs	AEI	2014	
		Industrial PhDs in health sciences and technology	ISCIII	2014	
	Financial rewards for public researchers that engage in knowledge transfer activities	Knowledge transfer sexennium	ANECA	2018 (pilot)	Culture and incentives
	Support for collaborative platforms and networks	Technology and innovation platforms	AEI	2005	Infrastruct.
		Networks for cooperative research-oriented health solutions	ISCIII	2013	
	Support for intermediaries in key infrastructures	Innovative business clusters program	MINCOTUR	2017	
		Cervera program for technology centers	CDTI	2019	

		Innovation Platform in Medical and Healthcare Technologies	ISCIII	N/A	
		Unique scientific and technical infrastructures	MICINN	N/A	
	Support for the creation of science- or technology-based spinoffs	NEOTEC Program	CDTI	2002	Funding
		INNVIERTE Program	CDTI	2012	
Promotion of entrepreneurship	Promotion of public–private coinvestment in scale-ups	Fond-ICO Next Tech	ICO	2022	
		Coinversión Innvierte Program	CDTI	2019	
	Spain Entrepreneurial Nation Strategy	50 measures, including the following: Startups Law, National Entrepreneurial Nation Brand National Office for Entrepreneurship.	Gobierno de España	2021	Infrastruct./Culture and incentives
Promotion of market demand for R&D	Promotion of public demand	Innocompra (renamed to FID)	MINCINN	2020	Demand
		Innodemanda	MINCINN	2020	
		Public innovation procurement	CDTI	2019	
Resolution of societal challenges	Promotion of major business R&D projects including participation from PROs	Science and Innovation Missions program	CDTI	2020	

Source: Own elaboration.

Partially based on OECD (2021).Moreover, over the last few months, the main public funding instruments have been financially reinforced (i.e., the Neotec program and Innvierte), thanks to the next generation funds[22]. However, as we have analyzed in previous subsections, the design of the current regulatory framework and policy instruments has not been adequately targeted to the needs of deep-tech entrepreneurs, and Spain lacks a specific strategy for the support of this typology of ventures.

The COVID-19 pandemic and its aftermath generated progressive awareness about the importance of science and innovation for solving societal challenges in Spain (García, 2021). Acknowledging the challenge that the country faces and its role in mitigating market failures (e.g., little private investment in R&D), systemic failures (e.g., little collaboration) and public value failures (e.g., social challenges) (Guimón, 2021), the Spanish government is currently involved in a series of profound regulatory reforms and changes. In this context, Spain will receive up to 140.000 million euros for reforms and investments coming from the “Next Generation EU” funds, which offer a unique opportunity for a change of paradigm toward mission-driven innovation and entrepreneurship based on deep technologies. Box 3 offers a summary of the key reforms and initiatives adopted in Spain with important impacts on deep-tech entrepreneurship.

Box 3: Key reforms and initiatives adopted in Spain impacting deep tech

Plan Nacional de Recuperación, Transformación y Resiliencia (PRTR): Composed of 10 levers and 30 components, this initiative articulates investments and reform projects and supports the distribution of "*Next Generation EU*" funds to stimulate recovery. The components impacting innovation policy are mainly the digitalization effort, the modernization of the industrial apparatus (lever 5), the promotion of science (lever 6, which includes *Component 17* supporting R&D intensive sectors, technology transfer and the development of public R&D initiatives), and training and human capital, specifically for improving digital skills. To implement the PRTR, Spain will receive up to 140.000 million euros (2021-2026) for reforms and investments, half of them as nonreimbursable transfers (Gobierno de España, 2021).

Especially relevant for deep tech, *Component 17* is directed toward the “*Institutional reform and strengthening of the capabilities of the national science, technology and innovation system*”, which includes the reform of the Law of Science Technology and Innovation (C17. R1), by promoting a new scientific career track similar to the “tenure track” but with better connections with the private sector (financed at 294,02 million euros – C17. I4) and technology transference, so that it is more highly valued at the individual and institutional levels (financed at 402,2 million euros – C17.I5). This component also aims at improving the coordination between different governance levels and establishes C17. R3 reform for the reorganization of PROs and the rationalization of their structure and functioning (Gobierno de España, 2021). It also establishes 5 measures to improve the functioning of TTOs, including the training of human capital, and defines horizontal objectives, such as improving knowledge transference and investments in key areas in initial phases (i.e., far from the market).

Spain Entrepreneurial Nation Strategy[23]: Takes innovative entrepreneurship as a priority, this strategy aims at attracting investment and establishes a new framework with four goals: 1) to accelerate the maturity of investment, 2) to attract and retain talent, 3) to promote the scalability of companies, and 4) to achieve an entrepreneurial public sector, which has an adequate regulatory frameworks and encourages investments of venture capital. There are 50 measures to support talent

[22] “The Ministry of Science and Innovation assigned 125 NEOTEC 2021 projects a total amount of 36,4 M€, 46% more than the previous year” – (News published 27/01/2022 by the Ministry of Science and Innovation). “The Ministry of Science and Innovation compromises 120 M€ for the Innvierte program for Technology Transference” – (News published 15/12/2021 by the Ministry of Science and Innovation).
[23] https://www.lamoncloa.gob.es/presidente/actividades/Paginas/2021/110221-sanchez_ene.aspx

and innovative entrepreneurship, including a) the creation of the **National Office for Entrepreneurship** to coordinate available services, b) the adoption of a **"Startups Law"** to facilitate the procedures for the creation of innovative ventures**,** and c) the implementation of a **"*National Entrepreneurial Nation Brand*"**. In addition, the *Startups Law* provides for a legal definition for startups, allocates an incentive-based tax regime, reduces bureaucratic procedures and introduces other incentives for employees and investors. However, as Hafied (2022) points out, deep tech is not explicitly targeted by the law, although some measures may have an impact on deep tech at the margin. For example, the definition of startup provides for an extension of the tax exemption by two years for companies in the biotechnology, energy and industrial sectors, those known for their technological intensity and which can be assimilated to deep tech. The bill also provides regulatory sandboxes for scientific experiments, as well as the creation of a forum for emerging companies that will encourage collaboration between public administrations, universities, TCs, research organizations and emerging companies (Ibid.).

Reform of the "Science, Technology and Innovation Law": The reform focuses on alleviating the precariousness of the research careers, on reducing excessive bureaucracy attached to obtaining research grants, and on implementing a system of sponsorship of startups by public administrations.

Reform of the "Organic Law of the University System" (LOSU): This reform aims to promote knowledge transference and collaboration between science, academia and industry and to reform the governance of universities, the modalities of financing universities and the rules inherent in technology transfer.

The **Science, Technology and Innovation Strategy** (*Estrategia de Ciencia, Tecnología e Innovación*, ECIT) was established for the period 2021-2027 by the Ministry of Science and Innovation and completed in 2021 by the plan for the period 2021-2023 (*Plan Estatal de Investigación e Innovación Científica y Técnica*, PEICTI).

As a result of this evolving context and initiatives, especially the PRTR, new financing instruments and funds have been created to target some of the weaknesses mentioned in our analysis. Box 4 details some of these new instruments.

Box 4: Description of selected new instruments relevant for deep tech

The "*Funding for proof of concept projects*" is provided by the State Research Agency (Spanish acronym: AEI) and directed toward the financing of development, valorization, protection, transference and exploitation activities, and in particular to the advancement of precompetitive technology development stages.

The "*Fond-ICO Next Tech*", which has 4.000 million euros for the scaling-up of startups based on disruptive digital technologies, will invest not only in companies but also in venture capital funds, hence promoting public–private collaboration and coinvestment.

The new Coinversión Innvierte program is for CDTI to coinvest with different specialized venture capital funds (i.e., Beable Capital, Bullnet Gestión, and Clave Mayor) in the capitalization of innovative TBCs located in Spain.

The Science and Innovation Missions Program was provided by CDTI with 95 million euros for major business R&D projects. These projects, led by companies, must include a very significant participation from PROs and must respond to important strategic challenges for the country (e.g., in 2021 eight challenges and missions were specified, which include, for example, safe and clean energy, sustainable mobility, enhancements to the agri-food sector, and support for the Spanish industrial revolution toward the 21st century).

Public Innovation Procurement (in Spanish: Compra Pública Innovadora), by CDTI, promotes precommercial public procurement with the objective of validating developed technological prototypes, which cover societal public needs, within the Spanish Public Administration.

The appearance of these new types of policy instruments illustrates the change in focus of the Spanish STI Policies from an understanding of innovation as a linear process toward an understanding of innovation as a systemic process that, among other things, needs to be directed toward solving societal challenges (Guimón, 2021). Table 7 shows an evident increase in the availability of policy instruments targeting important areas that will support deep-tech entrepreneurship, but it seems necessary to highlight that no specific "Deep-Tech Entrepreneurial Strategy" has been designed or envisioned yet.

It is too soon to know the efficacy of these new policy instruments, and hence, they will need to be assessed and evaluated in the upcoming years. In fact, policy evaluation has been a persistent failure of the Spanish government, and hence, it is an important weakness that needs to be corrected together with the gap in the effective execution of innovation policy budgets (Guimón, 2021).

3.4.2 Other initiatives

Building on the insight that intermediary agents are important catalyzers of the process of the conversion of knowledge into economic growth (Braunerhjelm et al. 2010), in Spain, some **public–private initiatives** are creating important role models as intermediary agents and successful deep-tech venture builders. This is the case of Tecnalia Ventures, a company owned by Tecnalia that aims at creating impact and value with the technologies originating in the research center, and The Collider[24], a public–private initiative set up by the *Mobile World Capital Barcelona Foundation*, with the support of the central government and local authorities. The Collider aims at connecting scientific and business talent to create deep-tech startups (OECD 2021) in the fields of digital health, industry 4.0, energy efficiency and sustainability and agriculture (#G). Additionally, other important initiatives exist in the country, although they are not specifically deep-tech oriented, aiming at building innovative and entrepreneurial ecosystems (e.g., South Summit).

In Spain, these relevant initiatives are geographically concentrated, and in fact, most high-tech innovation clusters are located in Madrid and former industrial areas, particularly in the Basque Country, Barcelona and Valencia, agglomerating key universities (e.g., *Universidad Politécnica de Madrid & Universidad Carlos III de Madrid, Universidad del Pais Vasco-Euskal Herriko Unibertsitatea, Universitat Politècnica de Catalunya,* or *Universitat Politècnica de Valencia*), technology centers, public research centers, spinoffs and other local companies.

This concentration of initiatives also attracts private equity and VC investment to these regions (ASCRI, 2021), and as a result, Madrid had a concentration of 59,6% of the total private capital investments in 2020 (6.275,2M euros), followed by Catalonia (10,3%), the Balearic Islands (7,6%) and the Basque Country (5,7%). For the specific case of deep-tech investment, Barcelona is Spain's leading hub[25], and numerous VC firms have made this city their home, including Origen Ventures, Ysios, and Alma Mundi (Hafied, 2022). In addition to The Collider, Barcelona also features other initiatives specifically dedicated

[24] The program offers support to innovative projects in their recruitment, market validation, or even valuation of intellectual property. In 2020, 40 pilot projects were supported with 10 partner companies, and since its creation in 2016, it has contributed to the creation of 14 spin-offs (OECD, 2021).
[25] 4,6 B euros invested locally between 2015 and 2021 (Ascri/Dealroom 2021).

to deep tech, such as the *Deep Tech Node* launched by the local development agency, *Barcelona Activa*, and several of the city's universities, whose aim is to encourage the creation of spinoffs by facilitating their access to the market (e.g., mentorships, presentation of projects to business angels, organization of the *Seed Deep Tech Barcelona* investment forum, recruitment assistance). Similarly, Valencia is the third major VC investment hub in Spain[26] and is home to several Spanish deep-tech VC funds, including Gohub and Clave Mayor[27] (Hafied, 2022). It is also involved in the *Inndromeda* project, an alliance that brings together several public and private actors to support deep tech (Ortega, 2022).

Summarizing the issues described in this section, Table 8 offers an overview of system weaknesses and of existing initiatives addressing them[28], although many of the included initiatives are not specifically targeted to deep tech and mainly address a specific aspect of the objective (e.g., industrial PhDs are not necessarily oriented toward deep tech or entrepreneurship but increase the practical experiences of researchers and improve their familiarity with business language).

[26] 506 M euros invested between 2015 and 2021(Ascri/Dealroom 2021).
[27] Recently, these firms were awarded a coinvestment mandate under the INNVIERTE program.
[28] For the same reasons as in Table 7, we do not claim it to be exhaustive, due to the low transparency of existing information.

Table 8: Summary of system weaknesses impacting I-Cap and E-Cap in deep tech and initiatives aiming at addressing them

WEAKNESS	GENERAL OBJECTIVE	INITIATIVES AIMING AT ADDRESSING SOME ASPECT OF THE WEAKNESS
HUMAN CAPITAL: An insufficient offer of people "fit" for deep tech, concentrated in some regions.	To have human capital with specific frontier science and technological knowledge that include the following: a) engaged in transforming this knowledge into solutions to real problems, b) familiar with the language of companies and investors, and c) trained in the practice of innovation and entrepreneurship.	**Public instruments** aim at the support of the *mobility and industry engagement of PhDs and postdocs* (e.g., Torres Quevedo, Industrial PhDs), *collaborative R&D projects* (Cervera R&D transfer, Science and innovation missions, Challenges), *the creation of science- or technology-based spinoffs* (e.g., Neotec, Innvierte), and *the promotion of major business R&D projects including participation from PROs* (Science and Innovation Missions program). Reform to the Organic Law of the University System (LOSU) **Other initiatives:** Tecnalia Ventures, The Collider, Wayra
FUNDING: Small amounts of available funds for deep tech and inadequate instruments	To increase the availability and amounts of public, private and coinvestment funds specifically oriented toward deep tech and to develop adequate instruments for funding these ventures	**Public instruments** aim at the support of the *creation of science- or technology-based spinoffs* (e.g., Neotec, Innvierte), of *collaborative R&D projects through grants and loans* (e.g., Cervera R&D transfer, Science and innovation missions, Challenges), *funding for proof of concept projects, funding for projects in strategic areas,* and the *promotion of public–private coinvestment in scale-ups* (Coinversión Invierte Program, Fond-ICO Next Tech) **Private initiatives:** Deep-tech oriented VCs (BeAble, Bullnet, Gohub Ysios...); The Collider, Seed Deep Tech Barcelona, La Caixa Impulse/Validate, Wayra...
MARKET DEMAND: Weak internal private and public market demand	To strengthen the public and private market demand for R&D scientific and technological results and frontier knowledge	**Public instruments** aim at the *promotion of public demand* (public innovation procurement, Innocompra, Innodemanda) and the *promotion of major business R&D projects including participation from PROs* (Science anda Innovation Missions) **Other initiatives:** Tecnalia Ventures, The Collider
INFRASTRUCTURE: Disarticulation of instruments for deep-tech support and specific barriers and weaknesses affecting support institutions	To increase the articulation, coordination and collaboration between institutions and reduce the complexity of the infrastructure, increasing transparency about existing instruments and policies, and to decrease the specific barriers affecting key support institutions.	**Public instruments** aim at support for collaborative platforms and networks (Technology and innovation platforms) and *intermediaries in key infrastructures* (Innovative business clusters program, Cervera program for technology centers, Unique scientific and technical infrastructures). PRTR (component 17), Spain Entrepreneurial Nation Strategy (National Office for Entrepreneurship)
CULTURE AND INCENTIVES: Highly conservative, cultural clashes and disincentives for entrepreneurial behavior in the academic/scientific arena	To increase the entrepreneurial spirit of scientists and researchers and the incentives for it, and to reduce the communication barriers existing between stakeholders for promoting collaboration	**Public instruments** provide *financial rewards for public researchers that engage in knowledge transfer activities* (knowledge transfer sexennia) Spain Entrepreneurial Nation Strategy (Startup Law), Reform to Science, Technology and Innovation Law, **Other initiatives:** Tecnalia Ventures, The Collider, FIK Research

Source: Own elaboration.

4 Next steps to promote deep-tech entrepreneurship

Complex problems require complex solutions, and as Budden and Murray (2018) state, structuring all the interrelated policy interventions needed to catalyze deep tech is a challenge, as *"no singular, 'magic bullet' policy solution exists".* Effective interventions need to be based on a profound understanding of the phenomenon of innovation and in this case, particularly the phenomenon of deep-tech innovation and the specific capacities of the region. In this regard, this report has offered an overarching view of the complex problem, but to properly solve each of the detected weaknesses and reach the generally envisaged objectives, a specific and profound analysis of each would be recommended to precisely define and structure the problems in ways that are recognizable, verifiable and solvable (Pérez-Breva, 2021). Moreover, effective interventions also require collaboration and cocreation between the different stakeholders of the ecosystem and even the dilution of boundaries between them or the opening of their action domains (Montes, 2020) across governmental levels, tiers and departmental responsibilities.

4.1. The role of the state

Different analyses have focused on the role of government and other public institutions in promoting deep-tech entrepreneurship and facing known weaknesses (e.g., OECD 2021, Hafied, 2022). Government intervention has been justified by the existence of market failures, systemic failures and failures of public value (Guimón, 2021). The preeminent role of public policy and of the state has been evidenced not only in Spain (Guimón, 2021) but also in many other countries (see Appendix 5 for a summary of some benchmark international initiatives for the support of deep-tech entrepreneurship), and it is important to learn from these other experiences[29].

This report has noted that new relevant policies and initiatives have recently emerged in Spain, which tackle some of the weaknesses affecting the five drivers of I-Cap and E-Cap, answer to recommendations made by different experts and by the EU and take advantage of the opportunities offered by the available European Funds. In fact, it seems that the Spanish government is increasingly aware of its role, not only as a promoter of R&D covering market failures but also of collaboration, technology transfer and cocreation and as an advocate for the solution of social challenges (Guimón, 2021) and for mission-driven entrepreneurship.

However, additional actions are needed, and it is important for the country, and for the state as its representative, to **develop a specific deep-tech-oriented vision and strategy,** with an inclusive nationwide approach that leaves behind the current fragmentation in governance**,** as the competitiveness and future of the whole country depends on it. Along this line, some institutions have elaborated policy recommendations focusing on the action sphere of government, with which we align in this report. Particularly relevant are those proposed by the OECD (2021) for the improvement of technology transference and collaboration and those proposed by the thinktank Real Instituto Elcano (Hafied, 2022) specifically for deep tech, as they define important priority areas, paths for action and specific measures (see Appendix 6 for a summary of selected key recommendations). We believe that a shared effort that

[29] As a selection of relevant initiatives, Hafied (2022) details the main deep-tech plans and deep-tech related measures conducted in France (i.e through the Deep Tech Plan entrusted to BpiFrance, with specific instruments such as the *French Tech Seed* grant or the *French Tech Emergence* Program), the UK (i.e., through several sectoral plans to support disruptive technologies, such as the *National Space Strategy*, and the creation of a *Breakthrough Innovation Fund* which will coinvest in disruptive technologies alongside private investors), Germany (i.e., through the *Deep Tech Future Fund* and federal agencies such as *Sprin-D*), Israel (i.e., through different initiatives closely linked and specialized in cybersecurity and weapons industries), and the US (i.e., with long-term public policies focused on cutting-edge sectors and intervention in technologies with strong market failures, and through the deepest VC industry in the world, which resulted from the reform of the ERISA Act of 1979, increasing the allocation of pension funds to VC firms).

reinforces the claims made by these institutions is necessary so that a clear and unified message is sent by the different stakeholders of civil society.

Putting together the insights offered in this report, we believe that the government should:

- **Keep some things going:** Intensify public–private collaboration, cocreation and knowledge transference by reinforcing the programs that have been positively rated by the stakeholders (e.g., Neotec, Invierte). Looking toward the upcoming years and the application of the PRTR and other newly created instruments, a more specific and detailed evaluation of policy instruments seems necessary to disentangle the "policy design" issues especially relevant to deep-tech support and deep-tech entrepreneurs.

- **Stop some things:** Very importantly, the state should create all the necessary mechanisms to stop the deindustrialization of the country. In addition, it should correct the "government failures" that have been preeminent in STI policies. Concretely, this means the following: a) reduce excessive bureaucratic burdens and improve the operative side of policy instruments, effectively executing available budgets, b) improve multilevel governance, reducing the complexity and opacity of the infrastructure and reinforcing cooperation[30], and c) improve the evaluation and assessment of policy instruments (Guimón, 2021).

- **Adapt new things:** It is too soon to know the impact of the recently developed policy instruments, but if deep tech is to be promoted, some of these initiatives should be adapted to the specific needs of this endeavor. For example, the "Spain Entrepreneurial Nation Strategy" should be adapted to explicitly consider the specificities and needs of deep-tech entrepreneurship. Similarly, other policy instruments should carefully reconsider and adapt the requirements and indicators used for assessment and verify their suitability in the real context of deep-tech ventures.

- **Start new things:** Solving these complex problems requires an inclusive approach that listens to the different voices and stakeholders, including deep-tech entrepreneurs, to cocreate with them the necessary changes. The current situation provides a unique opportunity to "think big" and create new types of public–private collaboration schemes that break the boundaries between traditional institutions, create shared spaces and incentives, and open their frontiers. In other words, it is necessary to evolve toward a new paradigm that extends the idea of a multipartisan pact on science, innovation and deep-tech impact-driven entrepreneurship to the whole society (Montes, 2020).

4.2. A multistakeholder perspective

The government is only one of the five key stakeholders in an innovation ecosystem, and hence, creating an equilibrated ecosystem requires additional actions and interventions coming from other actors. In Spain, there are key initiatives and institutions that facilitate important advances for I-Cap and E-Cap. In particular, we have analyzed the role of specific VC firms that are revisiting the investment model for deep tech and of other deep-tech venture builders (e.g., The Collider, Tecnalia Ventures) that play a critical role as catalyzers.

[30] The "Consejo Nacional de Ciencia Tecnología e Innovación (CONCYTEC)" was created to remedy coordination difficulties but appears not to be very effective and meets only infrequently (Hafied, 2022).

However, we believe that **the critical mass of these support initiatives from other key stakeholders in Spain is still insufficient** and that there is an opportunity to further develop and deepen the deep-tech ecosystem.

From a multistakeholder perspective, we offer a set of additional recommendations (Table 9) for action directed toward the five key actors of the ecosystem with a **unified mission: to make Spain an impact-driven and innovative entrepreneurial nation that is competitive at the international level in deep technologies transforming the world (for better).** Although the operative implementation of these actions requires the participation of all actors, we suggest that a specific stakeholder take the lead of each initiative as a representative and holder of specialist knowledge and expertise.

Table 9. Summary of recommendations

Recommendation	Leading stakeholder
Requirement: To elaborate a clear definition of deep-tech entrepreneurship agreed upon and applied by all stakeholders	Government
1. To develop an explicit deep-tech strategy	Government
2. To create an association of industrial deep-tech clients	Companies
3. To create a national club of deep-tech investors	Venture capital
4. To create an official deep-tech entrepreneurship and innovation school	University
5. To create a national deep-tech entrepreneurship summit	Entrepreneurs

Prerequisite: Elaborate a clear definition of deep-tech entrepreneurship

As a prerequisite for guiding all the actions, policies and instruments developed in the subsequent recommendations, it is necessary for Spain to elaborate a clear definition of deep-tech entrepreneurship based on immutable and objective characteristics of the ventures. This definition will recognize the special nature of the startups that apply for eligibility and allow for a better adjustment between the needs of these ventures and the specific public aid directed toward them. This definition should meet the following requirements: a) follow **organic definition criteria**, as suggested by Hafied (2022) and exemplified in the French deep-tech plan, and b) explicitly refer to the approach characterizing these ventures, that is, problem-oriented development of an “option space” that is broader than a specific product or solution (De la Tour et al., 2021; Pérez-Breva, 2017; Basilio et al., 2022).

The negotiations of this definition will be led by the High Commissioner for the Spain Entrepreneurial Nation Strategy (HCSEN) in the central government and coordinated with all stakeholders.

Recommendation 1. Develop an explicit Spanish deep-tech strategy

Although deep-tech innovation and entrepreneurship are affected by diverse policies, strategies and instruments, we consider it necessary for Spain to develop a unified and explicit deep-tech strategy that prioritizes this area for competitiveness and survival. This can take different shapes but should cover the key weaknesses of the current situation. Box 5 defines the particular aspects that the Spanish deep-tech strategy should consider.

Box 5: Particular recommendations for the design of the Spanish deep-tech strategy

(1) It should **create public aid schemes targeting the specific needs of deep-tech startups**. These schemes should be communicated in a transparent way and provide stable resources and calls for applications.

(2) It should **develop additional capacities for monitoring and evaluating the practical implementation** of the strategy of key policies and reforms (i.e., Box 3) **and of the obtained results in terms of the impact and value created.** This should be achieved by the following: (1) developing a **new battery of measures and indicators** better suited to the evaluation of deep-tech startups and their impact that is not only based on budgetary announcements or even execution, (2) creating a **policy evaluation committee** responsible for analyzing policy implementation, and (3) developing **correction mechanisms** for policy failures and inefficiencies.

(3) It should create a **permanent private–public roundtable in** deep tech, including the voices of different key stakeholders and governance levels (national, regional and local). In addition to identifying strategic technologies (Hafied, 2021), this permanent roundtable (or Council) should be in charge of the following: a) supervising the operativity and effective implementation of the deep-tech strategy, b) listening to the needs of key stakeholders, c) benchmarking other international deep-tech strategies, d) advising the central government on this topic, and e) making the government accountable for the implementation of the strategy.

(4) It should create a **"catalog" of all available instruments and support initiatives for deep tech** at all governance and institutional (public and private) levels, offering a single database for entrepreneurs with transparent information (i.e., supporting institution, prerequisites, funding, and timing, etc.).

(5) It should constitute a **national deep-tech venture builder program** following the example of successful initiatives at the national level (e.g., The Collider and Tecnalia Ventures) and at the international level (e.g., MIT ProtoVentures, and MA-based Flagship Pioneering).

(6) It should analyze the weaknesses of Spanish regulation and legislation particularly affecting deep-tech entrepreneurship and increase the facilities for "**doing business**" in Spain.

Through this explicit strategy and the specific support schemes and indicators, the Spanish government should **promote an entrepreneurial innovation model that aims to create employment, solve problems and create an impact and that shies away from more speculative models of entrepreneurship** (Pérez-Breva, 2017). In addition, the strategy should focus on changing the predominant symptoms of the current entrepreneurial ecosystem (i.e., low technology level, low value/impact and low scalability of the initiatives) that reveal the risks of the country falling behind.

Policies to meet these targets should be set by the central government through the High Commissioner for the Spain Entrepreneurial Nation Strategy (HCSEN). Although led by the HCSEN, other governmental organizations should be closely involved in the definition of the strategy, including state agencies dependent on the Ministry of Science and Innovation (i.e., CDTI, AEI) but also dependent on the Ministry of Industry, Trade and Tourism, the Ministry of Economic Affairs, and very importantly, regional governments. Through the permanent private–public roundtable in deep tech, representatives of corporations, venture capital, entrepreneurs and academia would also take part in defining the strategy and its supervision.

Recommendation 2. Create an association of industrial deep-tech clients

Because deep tech has a highly industrial component, many of the referenced studies and initiatives have emphasized the importance of strengthening the Spanish industry. In fact, lever 5 of the PRTR is directed toward the "*modernization and digitalization of the industrial fabric and of SMEs, recovery of tourism and impulse of Spain's entrepreneurial nation*", whereas *Component 12* focuses on the Industrial Policy Spain 2030 (Gobierno de España, 2021). This reinforcement should be achieved through the following: (1) increasing incentives for local R&D investment in the industry, (2) reducing current disincentives for engaging in collaboration (e.g., reforming accountancy rules and taxes, reducing bureaucracy, facilitating IP negotiations with public STIs) and (3) creating a Spanish industrial strategy that is aligned with the recommended deep-tech strategy (e.g., by directing specific support and promotion mechanisms to those industries that leverage cutting-edge technologies that can give Spain comparative advantages). These policies should learn from the industrial development experiences of the past (e.g., South Korea, Taiwan, Singapore), which were based on theories of linkages or forward and backward interconnections between technologies and industries.

In addition to the general reinforcement of the Spanish industrial fabric, we recommend that an additional specific emphasis be placed on the role of national industry as a deep-tech demander. For this purpose, we recommend that a specific association be created that gathers together Spanish industrial sectoral associations and representatives of industrial SMEs that would potentially benefit from deep-tech innovations originating in Spain.

This association should aim at promoting deep-tech innovation in different industries through different actions. These actions can include the following: (1) Jointly supporting R&D in specific strategic areas relevant for the members of the association; (2) Collaborating with PROs by identifying specific problems that require innovative deep-tech solutions; (3) Supporting researchers and emerging deep-tech startups in the "valley of death" by providing facilities for proofs of concept, scaling up and advancements in TRLs; (4) Demanding the results of these efforts in favorable market conditions be established with a win–win mentality, established in part by public funding and support; (5) Favoring a general revalorization of the industrial sector as a key actor for the competitiveness of the country (e.g., by organizing discussions and public debates about key opportunities and challenges for the industry); and (6) Maintaining constant communication with key stakeholders, importantly including deep-tech intermediaries, TCs, PROs, and **universities.**

Led by the corporate arena, the creation of the association should be promoted by the CEOE (i.e., Spanish Confederation Employers' Organizations) in collaboration with CEPYME (Spanish Confederation of Small and Medium-sized Enterprises) and other sectoral business associations.

Recommendation 3. Create a national club of deep-tech investors

There are still very few specialized deep-tech VC firms in Spain, and this situation creates a unique opportunity for advocacy for deep-tech investment. We recommend creating a National Club of Deep-tech Investors, led by venture capitalists with a track record of experience in deep tech, that aims at the following:

(1) Creating advocacy and reducing "fear" of deep tech among nonspecialized investors (e.g., sharing experiences, expertise and practices, such as success stories, applied selection criteria, indicators of progress well suited for deep tech, etc.).

(2) Discussing the weaknesses of the current investment model for supporting deep tech and creating specialized investment white papers for the government, other stakeholders and specifically for the "permanent private–public roundtable in deep tech".

(3) Creating additional instruments and coinvestment initiatives that increase the amount of funding for deep tech and that efficiently channel available funds to impact-driven initiatives. For example, these actors can reinforce the new public–private coinvestment initiatives (e.g., the Innvierte program) or create "funds of funds" directed to specific deep-tech projects with high potential and strategic interest for the country.

This may be led by SPAINCAP[31] and the main specialized deep-tech investors and venture capitalists (e.g., Bullnet, Beable, GoHub, Clave Mayor…).

Recommendation 4. Create an official deep-tech E&I school

We recommend creating training programs in innovation and deep-tech entrepreneurship that tackle the challenges that the current education model faces. In particular, we recommend that a deep-tech entrepreneurship and innovation school (DTEIS) be created at a higher education level. The DTEIS should aim at solving the main weakness affecting the lack of human capital "fit" for deep tech. In particular, it should aim to do the following: (1) train scientists and engineers at the frontiers of knowledge with the complementary capabilities required for deep-tech entrepreneurship (i.e., practical experiences with hands-on real problem approaches and "before-and-after experiences", internships in deep-tech startups, opportunities for interacting and collaborating with companies and investors, and access to facilities for prototyping and getting scientific knowledge to the market, etc.). (2) Train university professors in STEM subjects both in the practice of E&I and in the practice of teaching these key capabilities to their students (e.g., giving them access to experiences developed in other leading institutions with similar objectives). (3) Training employees working at Spanish TTOs in E&I and in all the theoretical and practical knowledge necessary for technology transference in deep tech. Moreover, this official school could be in charge of providing accreditations to TTO professionals as recommended by the OECD (2021).

In addition, we recommend that these types of carefully designed and practically oriented programs benefit from collaborations with prestigious entrepreneurial academic institutions with extensive experience in the promotion of deep-tech entrepreneurship and knowledge transfer and from the lessons learned in other successful initiatives (e.g., Catalyst, Proto Ventures, or iTeams, all initiated at MIT).

This aspect will be led by Universities and PROs, with the participation of TTOs, the Social Councils, ANECA, and regional governments. The official DTEIS should be cocreated with other stakeholders, such as educational institutions, foundations, technology centers, and governmental organizations (e.g., EOI, AEI).

Recommendation 5. Create a national deep-tech entrepreneurship summit

The literature has shown that academic entrepreneurs establish companies for various reasons, including maximizing profit, technology development, public service and the goal of applying knowledge to solve local and regional problems and create an impact, in addition to more personal goals, such as career enrichment, job creation, skill enhancement, influence of peers, or access to government grants (Bradley et al., 2013). However, our analysis of the different journeys of deep-tech entrepreneurs has shown the relevance of support institutions for creating "critical incidents" or "before-and-after experiences" in which

[31] SPAINCAP is the association that brings together venture capital & private equity firms in Spain, as well as their investors, including insurance companies and pension funds. https://spaincap.org/en/

the entrepreneurial path is discovered as an alternative to the traditional scientific path (e.g., deep-tech events, spaces for cocreation and collaboration) and in which a common ground for understanding and collaboration can emerge.

For this reason, a common effort is necessary to increase these types of “critical incidents”, increase the visibility of deep-tech entrepreneurship and its specific needs for changing the country’s entrepreneurial culture and increase general awareness about the opportunities of this strategic phenomenon. Thus, we recommend the organization of a national deep-tech entrepreneurship summit (organized in a different region each year) that aims at the following:

(1) Bringing together the different voices of key stakeholders to discuss different relevant issues (e.g., the scientific, entrepreneurial and innovation model that the country needs to support, the need to reevaluate the industrial fabric, new investment models better suited for deep tech, and the specific challenges of these ventures) so that the gap between their “different languages” is reduced, allowing for better collaboration.

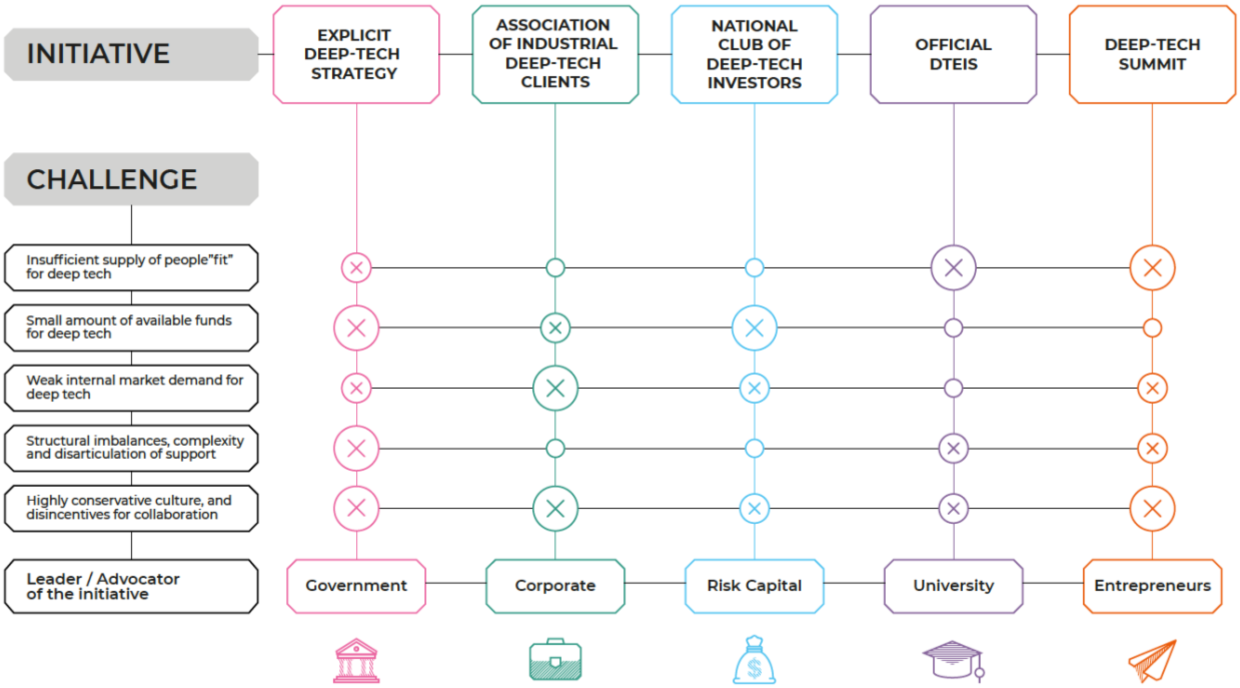
(2) Sharing successful support initiatives, ventures, experiences, investments, and “alternative scientific paths”; creating new role models and references that reduce perceptions about risk and reduce the fear of trying new things; attract additional actors to the ecosystem; and create a critical mass for change.

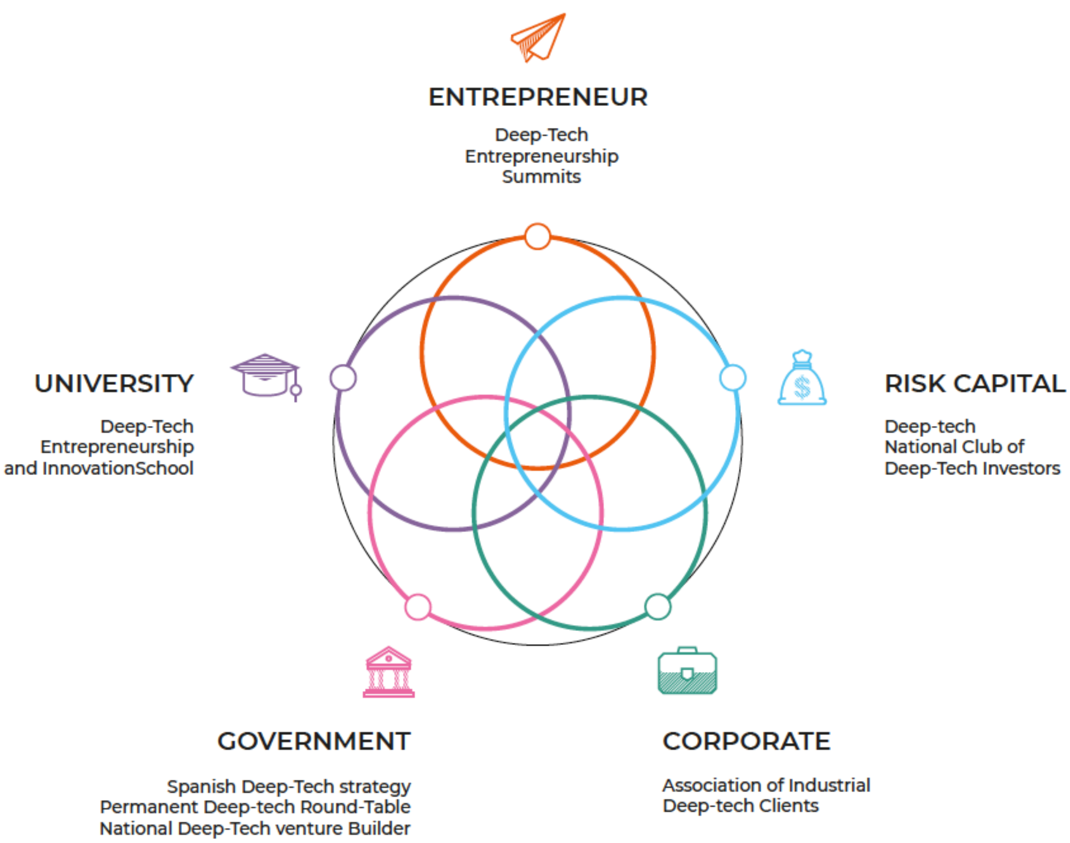
(3) Creating specific deep-tech challenges aimed at answering relevant societal needs, which mobilize the benefits of collective intelligence and action, crowdsourcing, and open innovation.

This element will be led by deep-tech entrepreneurs, who must gather information from all the different stakeholders and agents of the civil society, including associations, incubators, accelerators, foundations, and TCs, etc.

To summarize, Table 10 offers an overview of the recommended initiatives, linked to a) the stakeholder that we believe should take the lead in it and b) the main challenges affecting the five key inputs for I-Cap and E-Cap in the Spanish ecosystem that these initiatives particularly tackle.

Table 10. Overview of recommended initiatives to address the main challenges facing the Spanish deep-tech E&I ecosystem





5 Conclusion

The goal of this analysis has been to understand the Spanish ecosystem for fostering deep-tech entrepreneurship because of its high potential for impact and value creation. Identifying the main weaknesses facing the Spanish innovation and entrepreneurship scenario from a systemic point of view and understanding the specificities of this complex problem lead to clear diagnostic symptoms, as shown by entrepreneurship indicators related to technology level, growth and impact.

First, the analysis shows that, in Spain, it is still important to promote a specifically deep-tech-oriented strategy and to reduce the ambiguity of the official national and institutional definitions of deep-tech entrepreneurship. Clarity will lead to clear rules and delimitations that reduce complexity of governance and facilitate public understanding of this phenomena and its specific needs.

Moreover, following the I-Cap and E-Cap framework and the analysis of the interviews and the literature review, some important weaknesses have been highlighted specifically to foster deep-tech entrepreneurship.

There are no singular "magic bullets" or policy solutions for this complex problem, and it seems clear that we need a collection of policy interventions that engage many different agents: multilevel engagement of the different tiers of government, the scientific/academic arena, economic agents (corporations, entrepreneurs and venture capitalists) and society. We have described interesting initiatives for Spain to support deep-tech entrepreneurship.

However, the critical mass of initiatives is still insufficient, and the higher involvement of key stakeholders is needed. Emerging from the analysis of the challenges that Spain faces, we have proposed a battery of actions that require multilevel engagement and that are key for creating cultural change. These changes will allow more researchers to jump from academic tracks to deep-tech entrepreneurship and for more people from the industry and business arena to become engaged in science and technology and in high-impact problem-oriented entrepreneurship.

References

Acemoglu, D. and Robinson, J., (2012). *Why Nations Fails: The Origins of Power*, *Prosperity and Poverty*, Profile Books.

Acharya, V. and V. Subramanian (2009). *Bankruptcy Codes and Innovation*, The Review of Financial Studies, Vol. 22, Issue 12, pp. 4949-4988

Aghion, P., Antonin, C. and Bunel, S. (2021), The Power of Creative Destruction, Economic Upheaval and the wealth of nations, *Harvard University Press*

Aghion, P., Dewatripont, M. and Stein, J., C. (2008). *Academic Freedom, Private-Sector Focus, and the Process of Innovation*, NBER, WP 11542.

Akcigit, U., Baslandze, S. and Stantcheva, S. (2016). Taxation and the International Mobility of Inventors, *American Economic Review*, vol. 106, No. 10.

APTE (2022). Statistics. Retrieved from: https://www.apte.org/estadisticas

Arce, O. (2021): La crisis del covid-19 y su impacto sobre las condiciones económicas de las generaciones jóvenes. Intervención del DG de Economía y Estadística del Banco de España. Universidad de Alcala de Henares.

Ascri/DealRoom, (2021), *Spanish Tech Ecosystem*

ASCRI (2021), Informe ASCRI

ASCRI (2020), *Informe de actividad Venture Capital & Private Equity en España*

Autor, D., Dorn, D., Katz, F., L., Patterson, C., and Van Reenen, J. (2019). The Fall of the Labor and the Rise of Superstar Firms, *Quarterly Journal of Economics*, vol. 135, Issue 2, pp. 645-709

Basilio, O., F. Murray and L. Frolund (2022). What is “Deep Tech” and what are Deep Tech Ventures?, Working Paper. MIT Global Programs.

Basilio, O. and P. Gabaldón (2021). Enseñando emprendimiento para la innovación: una revisión sistemática de la literatura, *Revista de Economía Industrial*, nº421

BBVA (2021). *R&D in the private sector: Next Generation EU (NGEU) funds are not enough*

Bloom, N., J., Van Reenen and H. Williams,(2019), Policies to Promote Innovation, *Journal of Economic Perspectives*, 33(3): 163-184

Bolton, P. and Farrell, J., (1990). Decentralization, Duplication, and Delay, *Journal of Political Economy*, Vol. 98, Issue 4, pp. 803-826

Borrás, S. and Jordana, J. (2016). When regional innovation policies meet policy rationales and evidence: a plea for policy analysis, *European Planning Studies*, Vol. 24/12, pp. 2133-2153.

Bozio, A., Irac, D., and Py, L. (2014*), Impact of research tax credit on r&d and innovation: Evidence from the 2008 french reform*, Banque de France Working Paper 532, Banque de France.

Bradley, S., Hayter, C. S. and Link, A. N. (2013), Models and Methods of University Technology Transfer, *Foundations and Trends in Entrepreneurship* Vol. 9, No. 6

Braddon, D. (1999). *Commercial Applications of Military R&D: US and EU Programs Compared*, mimeo, University of the West of England

Braunerhjelm, P., Acs, Z. J., Audretsch, D. B., and Carlsson, B. (2010). The missing link: Knowledge diffusion and entrepreneurship in endogenous growth. *Small Business Economics*, 34(2), 105–125.

Brush, C., P. Greene, L. Balachandra and A. Davis (2018). The gender gap in venture capital: progress, problems and perspectives, *An International Journal of Entrepreneurial Finance* vol. 20 (2)

Budden, P. and F. Murray (2018). An MIT framework for innovation ecosystem policy: Developing policies to support vibrant innovation ecosystems (iEcosystems), Working Paper, MIT Lab for Innovation Science and Policy.

Budden, P. and F. Murray (2019). MIT's stakeholder framework for building and accelerating innovation ecosystems, Working Paper, MIT Lab for Innovation Science and Policy.

Byrne, D. and W. Griffitt (1973). Interpersonal Attraction*. Annual Review of Psychology*, 24, 1, pp. 317-336

Calel, R. and A. Dechezleprêtre (2016). Environmental Policy and Directed Technological Change: Evidence from the European Carbon Market, *The Review of Economics and Statistics*, Vol. 98, Issue 1, 173-191.

Cavero, J.M. and Ruiz, D. (2017). Educación para la innovación y el emprendimiento: una educación para el futuro. Recomendaciones para su impulso. Real Academia de Ingenieria

CCOO Industria (2017). Situación de la industria y evolución de la economía española

CRUE (2019). La universidad española en cifras. Resumen ejecutivo 2017/2018.

CRUE (2017). Creación de empresas de base tecnológica desde los centros públicos de investigación. Informes Técnicos RedOTRI. Crue Universidades Españolas (Ed)

CYD (2021). Ranking CYD

Cumming, D. (2007). Government policy towards entrepreneurial finance: Innovation investment funds*, Journal of Business Venturing*, 22(2), 337-356.

Cumming, D. and N. Dai (2010). Local Bias in Venture Capital Investments, *Journal of Empirical Finance*, 17, pp. 362-380

DealRoom (2021). *The year of Deep Tech*

DEEP Ecosystems (2021). Startup Heatmap Europe Report 2021: The power of the ecosystem. Retrieved from: https://startupsandplaces.com/shm2021-the-power-of-the-ecosystem/

De la Tour, A., M. Portincaso, N. Goeldel, U. Chaudhry, C. Tallec and A. Gourévitch (2021). *Deep Tech: The great wave of innovation*. BCG/Hello Tomorrow.

De la Tour, A., P. Soussan, N. Harlé, R. Chevalier, and X. Duportet (2017). From tech to deep tech: Fostering collaboration between corporates and startups. BCG/ Hello Tomorrow.

Deming, D., (2019), *STEM Careers and the Changing Skill Requirements of Work*

Egeln, J., Gottschalk, S., Rammer, C. and Spielkamp, A. (2003), *Spinoff-Gründungen aus der öffentlichen Forschung in Deutschland: Kurzfassung; Gutachten für das Bundesministerium für Bildung und Forschung*.

Etzkowitz, H. (2003). Research groups as 'quasi-firms': the invention of the entrepreneurial university, *Research Policy* 32: pp. 109-121.

European Commission (2021). European Innovation Scoreboard 2021.

EY (2021). *Baromètre EY du capital risque, Bilan 2020*

Fariñas,J.C., A. Martín, and F. Velázquez (2015). La desindustrialización de España en el contexto europeo, *Papeles de Economía Española nº 144*

Florida, R. (2002). *The Rise of The Creative Class: And How it's transforming work, leisure, community and everyday life*, Basic Book.

Fundación CYD (2020). Las universidades españolas. Una perspectiva autonómica.

Fundación Rafael del Pino (2021). "España a ciencia cierta". Coordinated by Javier García. Editorial Gestión 2000. ISBN: 978-84-9875-520-6

García, J. (2021). Informe INTEC. Diez tecnologías para impulsar a España. Fundación Rafael del Pino. Retrieved from: https://informeintec.org/informe-2021/

GEM Spain (2021). Global Entrepreneurship Monitor. Informe GEM España 2020-2021. https://www.gem-spain.com/informes-nacionales/

Ghio, N., Guerini, M., Lehmann, E. E., and Rossi-Lamastra, C. (2015). The emergence of the knowledge spillover theory of entrepreneurship. *Small Business Economics*, 44(1), 1–18.

Glaeser, E. L. (2013). *Consequences of Urbanization in Poorer Countries*, BBER, WP 19745

Gobierno de España (2021). Plan de Recuperación, Transformación y Resiliencia. Retrieved from: https://planderecuperacion.gob.es/

Gompers, P.A. (1994). The Rise and Fall of Venture Capital, *Business and Economic History* 23, no. 2, 1994, 1-24.

Gonzalez-Uribe, J. (2013). *Venture Capital and Innovation*, Columbia University

Gornall, W. and I.A. Strebulaev (2015). *The Economic Impact of Venture Capital: Evidence from Public Companies*, Working Paper No. 3362.

Gosh, S. and Nanda, R. (2010). Venture Capital Investments in Clean Energy Sector, *Harvard Business School,* WP 11-020

Guimón, J. (2021). La política de innovación en España: Evolución reciente y nuevos horizontes, *Revista de Economía Industrial*, nº421

Hafied, F. (2022). *Una estrategia nacional de Deep Tech para España*, Real Instituto Elcano.

Hafied, F., Rachiq, C. and Roulleau, G. (2021). *Venture capital and development of French start-ups*, Tresor-Economics, No. 276.

Hafied, F. (2019). *Capital-risque et financement de l'innovation : Évaluation des start-ups, modes de financement, montages*, DeBoeck.

Haskel, J., Goodbridge, P., Hughes, A. and Wallis, G. (2015), *The Contribution of public and private R&D to UK productivity growth*, WP 21171, Imperial College

Heirman, A. and Clarysse (2004). How and Why do Research-Based Start-Ups Differ at Founding? A Resource-Based Configurational Perspective, *The Journal of Technology Transfer*, 29, 247-268

Hellmann, T. and M. Puri (2000). The interaction between product market and financing strategy: the role of venture capital, Review of Financial Studies, *The Review of Financial Studies*, 13(4), 959-984.

Helm, R. and Mauroner, O. (2007). Success of research-based spin-offs. State-of-the-art and guidelines for further research, *Review of Managerial Science*, Vol. 1, Issue 3, 237-270

Hellow Tomorrow (2022). Deep Tech Investors mapping. Retrieved from the public version of the database.

Henderson, M. and Newell, R. G.,(2011). *Accelerating Energy Innovation: Insights from Multiple Sectors*, NBER.

Higgs, P., L., Cunningham, S., D. and Bakhshi, H., (2008). *Beyond the creative industries: Mapping the creative economy in the United Kingdom*, NESTA.

INE (2018) *Encuesta sobre innovación en las empresas*.

Jarchow, S. and Röhm, A. (2019). Patent-based investment funds: from invention to innovation, *The Journal of Technology Transfer* 44, pp.404-433

Kaplan, S. and P. Stromberg (2003). Financial Contracting Theory Meets the Real World: An Empirical Analysis of Venture Capital Contracts, *Review of Economic Studies*, vol. 70, 281-315

Kaplan, S. and Schoar, A. (2005). Private Equity Performance: Returns, Persistence, and Capital Flows, *Journal of Finance*, vol. 60, pp. 1791-1823

Kátay, G., Mosberger, P. and Tucci, F (2019). *The Impact of EU Grants for Research and Innovation on Private Firms' Performance*, European Commission.

Kornai, J. (2010). *Innovation and Dynamism: Interaction between Systems and Technical Progress*, Wider Paper Series, World Institute for Development Economic Research

Kortum, S. and J. Lerner (2000). Assessing the Contribution of Venture Capital to Innovation, *RAND Journal of Economics*, vol. 31, issue 4, 674-692

Kriegesmann (2000). Unternehmensgründungen aus der Wissenschaft. In: ZfB 70(4),S. 397-414

Krugman, P. (1991), Increasing Returns and Economic Geography, *Journal of Political Economy*, Vol. 99, Issue 3, pp. 483-499.

Langeber, C. (2021). Deep Tech Comunidad de Madrid. Retrieved from: https://ecosystem.madrimasd.org/industry-reports-in-madrid

Lerner, J., (1994). The syndication of Venture Capital Investments, *Financial Management,* vol. 23, n°3, 16-27.

Liu, F., Ma, J. and Li, R., (2019). Which Role Model Is More Effective in Entrepreneurship Education? An Investigation of Storytelling on Individual's Entrepreneurial Intention, *Frontiers in Psychology*.

Lockett, A., Siegel, D., Wright, M., and Ensley, M. D. (2005). The creation of spin-off firms at public research institutions: Managerial and policy implications, *Research Policy*, 34(7), 981-993

Lucas, R. (1988). On the Mechanics of Economic Development, *Journal of Monetary Economics* 22, 3-42.

Madri+d (2021). Deeptech startups and scaleups in Madrid Region. Retrieved from: https://ecosystem.madrimasd.org/lists/22303

Marquez, R., Nanda, V. and Yavuz, D., (2012). *Private Equity Fund Returns and Persistence, Review of Finance*, 19(5).

Marx, M., Singh, J., and L. Fleming (2015). Regional Disadvantage? Employee Non-Compete Agreements and Brain Drain, *Research Policy* 44 (2), 2015, pp. 394-404.

Mazzucato, M. (2015). *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*, Public Affairs.

Ministerio de Universidades (2021). Datos y cifras del sistema universitario español. Publicación 2020-

2021.

Montes, V.J. (2020). La imperiosa apertura del dominio público a la innovación y a la co-creación, TCEE, available in https://atcee.es/la-imperiosa-apertura-del-dominio-publico-a-la-innovacion-y-a-la-co-creacion/

Moretti, E., C. Steinwender and J. Van Reenen. (2019). *The intellectual spoils of war? Defense R&D, productivity and international spillovers*, NBER, Working Paper 26483.

North, C.D. (1990). *Institutions, Institutional change and economic performance*, Cambridge University Press.

OECD (2021). Improving knowledge transfer and collaboration between science and business in Spain. Diagnosis report: Assessment and recommendations. DSTI/STP (2021)18.

Ortega, A. (2022), *Industrializar la digitalización*, Real Instituto Elcano.

O'Shea, R., P., Allan, J., T., Chevalier, A. and Roche, F., (2005). Entrepreneurial orientation, technology transfer and spinoff performance of U.S. universities, *Research Policy*, vol. 34, Issue 7, 994-1009

Pérez-Breva, L. (2017). *Innovating: A doer's manifesto for starting from a hunch, prototyping problems, scaling up and learning to be productively wrong*, The MIT Press.

Person, K., D. Cohen, J. Miller and F. Murray (2019). NSWC Crane Innovation Analysis: Contributing to regional innovation ecosystems, MITii

Porter, M. E. (2000). Location, Competition and Economic Development: Local Clusters in a Global Economy, *Economic Development Quarterly* 14.

Portincaso, M., Q. Gourévitch, A. de la Tour, A. Legris and T. Hammoud (2021). The deep tech investment paradox: a call to redesign the investor model. Report by BCG and HelloTomorrow.

Puri, M. and R. Zarutskie (2008). *On The Lifecycle Dynamics of Venture-Capital and Non-Venture-Capital-Financed Firms*, NBER

Rothwell, R. and Zegveld, W. (1981). *Industrial Innovation and Public Policy: Preparing for the 1980s and 1990s*, Frances Printer, London, 10-12

Saxenian, A.L. (1990). Regional Networks and the Resurgence of Silicon Valley, *California Management Review*, Berkeley, vol. 33, n. 1

Senor, D. and Katz, S. (2009). *Start-up Nation: The Story of Israel's Economic Miracle*

Siegel, D.S., D. Waldman, and A. Link. (2003). Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: an exploratory study, *Research Policy* 32, pp.27-48

Smilor, R. and Matthews, J., (2004). University Venturing: Technology Transfer and Commercialisation in Higher Education, *International Journal of Technology Transfer and Commercialisation*, 3(1).

Stern, S. (2004). Do Scientists Pay to Be Scientists?, *Management Science*, Vol. 50, Issue 6.

Stuart, T.E., and O. Sorenson. (2003). Liquidity Events and the Geographic Distribution of Entrepreneurial Activity, *Administrative Science Quarterly* 48 (2), pp. 175-201

The Collider (2019). La transferencia de tecnología y la empresa. Retos y oportunidades. The Collider. Una iniciativa de Mobile World Capital

Trenado, M. and E. Huergo (2007). Nuevas empresas de base tecnológica: una revisión de la literatura reciente, Documento de trabajo 03, CDTI.

Uyarra, E. and Flanagan, K. (2009). Understanding the Innovation Impacts of Public Procurement, *European Planning Studies*, vol. 18, Issue 1, 123-143.

Vohara, A., Wright, M. and Lockett, A., (2004). *Critical junctures in the development of university high-tech spinout companies*, vol. 33, Issue 1, 147-175

Zhang, J. (2011). The advantage of experience start-up founders in venture capital acquisitions: Evidence form serial entrepreneurs, *IZA Discussion Papers*, N. 2964

Appendix 1: The MIT framework for innovation ecosystem policy

The *MIT iEcosystem framework* offers a comprehensive and simple understanding of the system that allows for the creation and growth of IDEs by decomposing the system into four elements (Figure A).

Figure A: The system for innovation-driven entrepreneurship

Source: Budden and Murray, 2018

These elements are the following: 1) the **foundational institutions** often taken for granted (e.g., rule of law, protection of property rights, freedom for new ideas); 2) the **two critical capacities** that interact as twin engines for innovation, that is, **I-Cap** (i.e., the capacity of a place to develop "new-to-the-world" ideas and to translate science and research "from inception to impact" by transforming it into solutions that truly solve problems) and **E-Cap** (i.e., the more general capabilities and conditions for creating enterprises); 3) the **comparative advantage** of the region's economy; and 4) the generated **impact**, which results from the combination of I-Cap and E-Cap with core comparative advantages. According to this framework, it is the combination of and linkages between I-Cap and E-Cap within a country that are critical to producing high-impact IDEs.

a) I-Cap and E-Cap: Definitions, concepts, and literature review

Thinking of "capacities" as a sort of "production function" that relates specific inputs to outputs, the framework defines five input categories, drivers or dimensions for I-Cap and E-Cap, which need to be defined and optimized. Within each dimension, a variety of policy levers can be used to enhance access to these resources or inputs, which have shown different levels of effectiveness.

These five components or drivers are as follows:

1) Human capital

At the microeconomic level, capital is anything that is likely to generate a future flow, and hence, human capital can be understood as a stock that materializes the productive potential of an individual and of a country's talent base. In this case, it can be considered the appropriate talent base in a region or country for either innovation or entrepreneurship. The increase in human capital depends on the personal investments of individuals and on public investment in R&D, as part of this investment is captured by individuals (Lucas, 1988).

Levers affecting this base include education and mobility policies that allow the mobility of individuals and ideas across organizations and knowledge spillovers but also "noncompete agreements" (NCAs), which hinder the circulation of ideas (Marx, Singh and Fleming, 2015) and are negatively correlated with the number of patents filed and startups and jobs created (Stuart and Sorenson, 2003).

2) Funding

The financing of innovation and entrepreneurship can come from public funds (subsidies, tax credits, grants) and private investments (venture capital), which at the same time can be incentivized by public authorities, who can take measures to direct savings toward innovative companies. Hence, policy levers include both direct measures and those that provide incentives for capital to flow to IDEs throughout their lifecycles (e.g., R&D spending, tax policies, investment policies, public-listing requirements).

Innovation grants or subsidies are a very common form of direct public financing to support innovation (Kátay, Mosberger and Tucci, 2019). These may concern a specific stage of a company's development (e.g., prototyping, purchasing of R&D equipment), a research project, a sector identified as being particularly capital-intensive in R&D, or an individual. In the case of individuals, subsidies most often take the form of research grants. Tax instruments can also be used to encourage innovation directly (e.g., through tax credits based on the size of the company or on R&D expenditure[32]) or indirectly (e.g., through the level of taxation of marginal income or corporate tax rates[33]).

From the private investment perspective, venture capital (VC) plays a key role in the ecosystem for supporting deep-tech ventures, particularly as it helps to overcome the problem of information asymmetry and to correct the risks of adverse selection (i.e., bad projects may succeed in raising funds) and moral hazard (i.e., high cash burn and careless management of funds by the executive team), inherent in deep-tech projects (Hafied, Rachiq and Roulleau, 2021). However, this mode of financing remains elitist (Puri and Zarutskie, 2011) and subject to numerous biases (Cumming and Dai, 2010; Byrne and Griffit, 1973; Zhang, 2011; Brush, Greene, Balachandra and Davis, 2017); hence, it is important to explore the conditions of these funding resources in a country.

3) Infrastructure

Innovation infrastructures are the set of physical facilities and regulations that have an impact on innovation and entrepreneurship. Investment in the physical infrastructure of innovation promotes productivity and is affected by policy levers such as planning/space policies, the regulatory infrastructure, digital policies and other policies affecting the use of specialized technical equipment.

According to Krugman (1991), the decision of agents where to base their venture depends on a circular logic: Firms seek to be close to markets where there are many consumers, and individuals (hence, consumers) are attracted to places where there are many firms. When a territory concentrates particularly innovative firms and physical infrastructures, it will tend to attract highly qualified individuals, and hence, places with a high concentration of so-called creative organizations and individuals (Florida, 2002) are, on average, more innovative (Higgs, Cunningham and Bakhshi, 2008; Glaeser, 2013). Clusters are specialized and integrated industrial districts that promote innovation and generate positive externalities due to the agglomeration effects of knowledge infrastructures (i.e., universities, science parks) and the highly qualified human capital that they attract, which spread knowledge spillovers (Saxenian, 1990; Porter, 2000).

[32] The positive effect of these measures has been evidenced in countries such as the UK (Calel and Dechezlepretre, 2016) and France (Bozio, Irac and Py, 2014).
[33] A high marginal income or corporate tax rate has been shown to negatively affect innovation (Akcigit, Baslandze and Stantcheva, 2016).

However, highly interventionist and vertical industrial policy has been subject to criticism since the 1980s, as it tends to favor biased selection (or *cherry picking*) and industrial concentration around domestic champions or "superstar firms" (Autor, Dorn, Katz, Patterson and Van Reenen, 2019). Defenders of vertical policy emphasize the legitimacy of government intervention in the presence of market failures such as those that occur often in the case of deep tech (e.g., resulting from asymmetric information on future returns, high entry barriers and the high capital intensity of projects). Hence, in this case, it seems necessary to create incentives for entering emerging technology markets and to subsidize first entrants (Bolton and Farrell, 1990).

In particular, universities and research organizations are especially relevant infrastructures, as they play a leading role in innovation and in basic research (Haskel, Goodbridge, Hughes and Wallis, 2015), which sets the technological frontier. It therefore seems crucial for public decision-makers to promote policies that increase the attractiveness of careers in university and public research and the retention of talent by these institutions.

4) Demand

The level and nature of specialized demand for the outputs of IDEs is a major determinant for innovation, and public authorities play an important role in stimulating it. Specialized demand is affected by policy levers that provide incentives for different organizations to support the purchasing of innovation and cooperation. These levers include public sector procurement, innovation subsidies, prizes, and grants, which can drive innovation toward specific national objectives and missions and in particular, measures to encourage technology transfer.

Technology transfer includes all the measures that allow for the civil application of R&D to be encouraged and involves subsidies and the work of technology transfer offices (TTOs) attached to universities and research centers, whose function is to identify and develop R&D projects with commercial potential. These transfers can also take the form of university spinoffs, i.e., high-tech startups created from academic R&D results. Another preferred instrument for promoting technology transfer is public procurement, which can be likened to a form of subsidy and whose intensity is correlated with innovation propensity (Uyarra and Flanagan, 2009; Henderson and Newel, 2011; Rothwell and Zegveld, 1981). With this tool, public authorities ensure a market for an innovative product, sometimes even before it is designed, and hence, encourage producers to launch R&D projects.

5) Culture and incentives

North (1990) distinguishes two types of institutions that have an effect on innovation through their impact on incentives: formal institutions (e.g., intellectual property rights, laws and regulations in social and financial matters) and informal institutions (e.g., culture, values, religion and beliefs, trust, and mental models). Hence, this dimension also includes the nature of role models and individuals who are celebrated, incentives that shape individual and team behaviors (e.g., regarding technology transference, cooperation, and career choices, etc.) and other social norms affecting innovation and entrepreneurial choices.

Policy levers affecting culture and incentives are directed toward the whole life cycle of deep-tech ventures, from universities' research assessment to intellectual property (IP) rights and licensing[34], to bankruptcy laws[35], competition law and other policies affecting institutional barriers, such as excessive bureaucracy or governance problems. Incentives also relate to career choices, and this seems especially relevant for deep tech, since university researchers are less well paid than those who work in companies

[34] The granting of IP rights to innovators is conducive to innovation and to the diffusion of knowledge.
[35] The tendency of a legal system to favor either debtors or creditors is not neutral for innovation (Acharya and Subramanian, 2009).

(Stern, 2004), which tend to favor applied research with more certain returns. However, salary is not the only determining factor of career choices in research, and these also depend on a trade-off between remuneration, academic freedom (Aghion, Antonin, and Bunel, 2021; Aghion, Dewatripont, and Stein, 2008) and other motivational factors.

The influence of informal institutions on innovation is more difficult to assess, as it makes use of fewer quantitative observations. However, the positive influence of entrepreneurial role models in encouraging vocations and positively influencing willingness to engage in entrepreneurship has been empirically evidenced (Liu, Ma and Li, 2019), and open-mindedness, democracy and transparency are considered vectors of innovation (Kornai, 2010; Acemoglu and Robinson, 2012).

b) The ecosystem perspective: key stakeholders

The *MIT stakeholder framework for building and accelerating innovation ecosystems* (Budden and Murray, 2019) allows for the understanding of the systemic roles played by the five key stakeholders required for building innovation ecosystems: corporations, venture capital, entrepreneurs, academia and government.

- **Entrepreneurs** play a central role in the ecosystem, and their voice is critical for the policies and actions to have an effect and not just result from what other stakeholders consider necessary for IDEs. The entrepreneurial journey experienced by deep-tech entrepreneurs and their perceptions about barriers and catalysts differ widely among sectors; hence, it is important to have a broad understanding of entrepreneurial phenomena. To identify the key success factors of spinoffs, some authors (e.g., Kriegesmann, 2000; Egeln, Gottschalk, Rammer and Spielkamp, 2003) have focused on motivational issues and other characteristics of the founders (e.g., autonomy, risk profile, willingness to escape university bureaucracy and hierarchy), while other authors (e.g., O'Shea, Allan, Chevalier and Roche, 2005; Vohara, Wright and Lockett, 2004; Smilor and Matthews, 2004; Lockett, Siegel, Wright and Ensley, 2005) have emphasized environmental factors (i.e., availability of capital, ease of patenting and IP transfer conditions, available mentorship, networks and relationships with the ecosystem), and the level of maturity of the underlying technology (Heirman and Clarysse, 2004; Helm and Maurorer, 2007).
- **Venture capital** also plays a key role in the innovation ecosystem. Analysis can provide an important window into the factors that may limit the availability of venture capital resources. In the case of deep tech, it is important to explore the spectrum of venture capital resources, as not only VC[36] but also other forms of non-VC "*patient capital*" are key: e.g., business angels (individual investors often involved in early stages), corporate venture capital (CVC) (investment vehicles backed, managed, and owned by a large company, such as GV for Alphabet, IBM Ventures, Oracle VC, and GoHub by GlobalOmnium, etc.), and even crowdfunding (investment through digital platforms by nonexpert individuals). Moreover, as stated, VC plays other important roles, as it helps overcome problems of information asymmetry (Hafied et al. 2021), by reducing the risks of adverse selection. The sectoral expertise of the VC investment team and the syndication

[36] Venture capital also includes investment companies that may be specialized by sector (biotechnology, ICT), or that focus on one of the segments of the start-up financing continuum (seed capital, early stage or late-stage investment companies). These investment companies (general partners or GPs) collect savings from passive investors (insurance and asset management companies, foundations, family office funds, pension funds) whose management responsibility is limited (limited partnerships or LPs) within investment vehicles (special purpose vehicles). They have to invest the funds for a period of 7 to 10 years on average, at the end of which the holdings have to be liquidated in order to compensate the LPs (Hafied, 2019). GPs are responsible for their management to the LPs and are remunerated with a fixed part and a variable amount called "carried interest" which represents approximately 20% of the capital gain realized on the proceeds of the sale of the investments (Kaplan and Schoar, 2005). Marquez, Nanda and Yavuz (2012) point out that the performance of the funds managed by the GPs conditions subsequent fundraising.

of investments mitigate risk (Lerner, 1994; Cumming, 2007) and reduce moral hazards through stage financing (Cornelly and Yosha, 2003) and the inclusion of dilutive option clauses in investment contracts (Kaplan and Strömberg, 2003). Beyond that, VC also plays a role in identifying new ideas, talented teams and IDEs, and it has a positive effect on R&D (Gornall and Strebulaev, 2015; Gompers, 1994; Kortum and Lerner, 2000; Gonzalez-Uribe, 2013) reducing the time to market (Hellmann and Puri, 2002).

- **Universities** play a multifaceted role and are crucial for innovation (Etzkowitz, 2003), providing resources such as novel science-based ideas, technical and scientific training, sophisticated facilities, talent, etc. Those who engage with universities include a variety of actors, ranging from individual faculty and their labs to technology transfer offices (TTOs) and other centers and programs.
- **Corporations** play an important role in ecosystem building, as they contribute to venture capital through corporate venture capital (CVC), provide facilities that support innovation infrastructure and provide talent and "on the job" development. Very importantly for deep tech, large corporations play a key role in the value chain, both in demanding deep-tech solutions and providing key inputs, such as technologies. Moreover, large corporations often provide the means for scaling smaller deep-tech ventures, through acquisitions and as a means for exit.
- **The government** at its different levels (e.g., national, regional, local) plays a critical role in ecosystem building, and its presence and interaction with different organizations and individuals can be critical in shaping appropriate rules, norms and incentives within the ecosystem. The presence of high barriers to market entry for launching a deep-tech business (see Section 3.1.1) legitimates the intervention of the state to compensate for the weakness of private incentives to launch a deep-tech project (Gosh and Nanda, 2010). In fact, according to various authors (e.g., Bloom, Van Reenen and Williams, 2019; Braddon, 1999; Moretti, Steinwender and Van Reenen, 2019), defense R&D remains the most effective lever for increasing civilian innovation. As Mazzucato (2015) emphasizes, most of the major technological innovations have had a military origin and were initially launched by public authorities (e.g., the http/html protocol and GPS emerged from the DARPA program and the NAVSTAR research program, respectively, both launched by the US Defense Department), and the case of Israel also confirms this role of government in deep-tech innovation and entrepreneurship (Senor and Katz, 2009).

Appendix 2: Profiles of the interviewees

#	Gender	Profile (E-journey)	PhD	Specific knowledge	Startup tech./industry	Origin and characteristics of the startup
1	M	From student to entrepreneur	No	Aerospace + Naval	Drones/consumer products	University entrepreneurship competition
2	F	From researcher to research manager to entrepreneur	Yes	Genetics	Biotech/Health care	"traditional" spinoff
3	M	From student to industry to research to entrepreneur	Yes	Aerospace	Nanotech and industry 4.0/Aerospace	No spinoff, but university origin and collaboration
4	F	From researcher to industry to researcher to multiple-entrepreneur	Yes	AI and computer eng.	AI/Agro-alimentary AI/Consumer products	Multiple entrepreneur
5	F	From student to entrepreneur	No	Aeronautical	Rigid wingsale/automotive & environment	Career final Project/ selected by Hellotomorrow
6	F	From researcher to entrepreneur	Yes	Organic chemistry	Biotech/Health care	"traditional" spinoff
7	M	From researcher to academia and management to entrepreneur	Yes	Telecom	Kinect/Healthcare	Professor and entrepreneur
8	M	From industry to entrepreneur to research	No	Industrial eng.	Nanotech	Investment support from specialized VC

9	M	From industry to entrepreneur	No	Political Science and Sociology	AI/SaaS for energy efficiency	Selected by The Collider
10	M	From researcher to entrepreneur to researcher	Yes	Telecom & applied physics	Photonics/Sensors	Investment support from specialized VC + CSIC
11	M	From industry to researcher to entrepreneur	No	Electrical and electronics	Medical devices/Health care	Selected by Tecnalia Ventures

#	Gender	Profile	Organization
A	M	Professor and EU expert	Spanish public university
B	M	Professor and innovation expert	US university
C	F	UTTO experience and PhD in entrepreneurial universities	Spanish public university
D	F	Deep-tech-specialized corporate investor	Corporate venture capital
E	M	Head of best-practice TTO program (Deep-tech venture builder)	Spanish research institution
F	M	Deep-tech-specialized investor	Deep-tech venture capital
G	M	Head of best-practice TTO program (Deep-tech venture builder)	Deep-tech venture builder
H	M	Head of National Innovation Agency	National Innovation Agency

Appendix 3: Deep-tech investors based in Spain (with HQ in Spain)

	Name	Type	DT only	Size of current DT fund	Pre-seed	Seed	Series A	Series B+	Min ticket	Max ticket
1	**BeAble Capital**	VC	**Yes**	€35M	x	x	x		€100 K	€3M
2	Nina Capital	VC	No	€20M	x	x			€150K	€800K
3	Repsol Energy Ventures	CVC	No	€85M			x	x	$5M	$20M
4	Telefonica Ventures	CVC	No			x	x		€150K	€6M
5	Amadeus Ventures	CVC	No			x	x			
6	Axon Partners Group	VC	No			x	x			
7	**Bullnet Capital**	VC	**Yes**	€42.2M		x	x	x	€1M	€1.5M
8	Caixa Capital Risc	CVC	No	€20M		x	x	x		
9	Capital Energy Quantum	CVC	No	€20M		x	x	x		
10	Draper B1	VC	No	€11.3M		x				
11	Elewit	CVC	No		x	x	x			
12	Enagas Emprende	CVC	No			x	x			
13	Encomenda	VC	No			x			€70K	€300K
14	**Gohub**	CVC	**Yes**			x	x	x	€500K	€3M
15	Inveready	VC	No	€50M		x	x			
16	JME	VC	No	€60M		x	x			
17	**Origen Ventures Fund**	VC	**Yes**	$10M		x				
18	Propel Venture Partners	CVC	No			x	x			
19	Sabadell Venture Capital	CVC	No	€60M		x	x	x	€200K	€1M
20	Santander Innoventures	CVC	No	$200M		x	x	x		
21	Seaya Ventures	VC	No	€85M			x	x		
22	**Ysios Capital**	VC	**Yes**	€126.4M		x	x	x	€1M	€13M

Source: Own elaboration with data from HelloTomorrow

Appendix 4: Key infrastructures impacting deep tech in Spain

Institution	Description
Public Universities	83 universities: 50 public and 33 private (Ministerio de Universidades, 2021) Role: Main actors in the execution of R&D and training new researchers (OECD, 2021). Governance: Endowed with great formal autonomy but largely dependent on the funding received by the autonomous regions. Location: Over the whole territory, but highly concentrated in Madrid (14), Cataluña (12) and Comunitat Valenciana (9).
Unique scientific and technical infrastructures (Spanish acronym: ICTS)	Role: Promote access to frontier research infrastructures and related services, open to competitive access by the entire research community, including public and private R&D actors. Related to different research and knowledge areas (e.g., health and biotechnology, energy, engineering, materials etc.). Governance: Central government, through MICINN Location: Distributed across the whole national territory (map of ICTS) and considered strategic.
Public Research Organizations (PROs; Spanish acronym: OPIs)	Role: Basic and applied research. Some are aligned to regional strategic industries and are focused on basic research but with an orientation toward creating links with the industry (OECD, 2021). Governance: Linked to the central government at the national level (e.g., CSIC, CNIC, CNIO) or to the regional administrations (e.g., CERCA in Cataluña, BERC and CIC in the Basque Country, and IMDEA in Madrid). Location: Distributed across the national territory but geographically concentrated
Technology Centers (TCs)	Role: Important role as intermediaries between the research base and companies, and as developers of applied research. Linked to the autonomous regions in which they are based, they provide specialized infrastructure related to general technological areas or to specific industries that are strategic to the territory (OECD, 2021). Governance: Regional administrations. Location: Tecnalia in the Basque Country is the biggest, followed by Eurecat in Catalunya, which promotes technology-intensive R&D projects in many areas (e.g., biotech, industrial designs, digital development, sustainability).
Science and Technology Parks	51 STPs are members of APTE association (APTE, 2022). Role: Specialized technical equipment and infrastructure for the incubation and acceleration of companies, often with close linkages to public universities. Governance: Initiatives developed by regional governments Location: Distributed across the whole national territory.

Source: Own elaboration.

Appendix 5: Examples of plans and deep-tech-related measures implemented in several developed countries

Measures	France	United Kingdom	Germany	Israel	United States
Public (or parapublic) investment fund	Mission French Tech French Tech Seed French Tech Emergence Aide au développement Deep Tech Concours i-nov, i-lab, i-PhD Prêts à l'industrialisation Deep Tech	Breakthrough Innovation Fund	Future fund (*Zukunftsfonds*)	NOFAR, KAMIN, MAGNETON programs	America's Seed Fund In-Q-Tel fund
Technology transfer programs	Sociétés d'accélération et de transfert technologique (SATT)	Universities' Technology Transfer Office (TTOs)	Fraunhofer-Gesellschaft Fraunhofer Tech Transfer Fund	Israel Tech Transfer Organization	Bayh-Dole Act Small Business Technology Transfer
Tax incentives	Jeunes entreprises innovantes Crédit d'impôt recherche (CIR) Crédit d'impôt innovation (CII)	SME R&D tax relief Patent box tax relief	Fiscal incentive to R&D	Capital gain on sale of intellectual property Tax exemptions for high-tech workers working abroad	Regular Research Credit (RRC) Alternative Simplified Credit (ASC) Credit for basic research
Specific sectoral plans	Plan Deep Tech Stratégies d'Accélération Plan « France 2030 »	National Space Strategy National AI Strategy Joint Action Plan on Standards for the Fourth Industrial Revolution	Industry 4.0 National AI Strategy	Cybersecurity programs (KIDMA, MASAD)	National Nanotechnology Initiative Drug Orphan Act

Administra-tions in charge	MESRI, Laboratoires publics de recherche (CNRS, Inria, Inserm, IRSTEA, CEA, Inrae), SATT, Bpifrance, Universités publiques, Agence de l'innovation de Défense	Innovate UK Specialized research institutes (Babraham Institute, Daresbury lab, British Department of Health), J-Hub	Fraunhofer-Gesellschaft Helmholtz Association Max-Planck-Gesellshaft Academies Liebniz association Public universities	Israel Innovation Authority, MAFAT, 8200 Unit, Ministry of Defense	SBIR, Darpa, Small Business Technology Transfer, NSF, Small Business Administration

Source: Hafied (2022).

Appendix 6: Selected key recommendations directed toward government action

Document	Key recommendations
"Knowledge transfer and collaboration between science and business in Spain" as elaborated by the OECD (2021).	Directed to six priority areas to enhance public research–business collaboration, which, although **not explicitly directed to** deep tech, include highly relevant recommendations: 1- Put in place firm systemic foundations and enabling conditions for science and innovation, including stable resources and policy frameworks. 2- Implement effective governance of universities and public R&D centers: missions, autonomy and accountability to serve society. 3- Align individual and institutional incentives to decisively and effectively promote transfer and collaboration. 4- Activate and coordinate public–private intermediary agents, promoting their professionalization and action on an optimal scale close to market. 5- Prioritize company development of innovation capacities and interaction with the public research base. 6- Strengthen intelligence and policy evaluation capacities for the constant improvement of policy design and implementation.
"A national deep-tech strategy for Spain" elaborated by Hafied (2022) for Real Instituto Elcano	1- The creation of a National Deep Tech Strategic Council composed of different independent experts in charge of identifying and selecting ten cutting-edge technologies[37]. 2- The establishment of a definition of deep-tech startups based on organic criteria and the creation of a "deep-tech label" for accessing priority aid schemes. 3- The reinforcement of the mobility of researchers. 4- The rationalization and professionalization of Spanish TTOs and creation of "technology transfer acceleration companies". 5- The constitution of a Spanish ARPA. 6- The reform of the Spanish university.

[37] Since 2019, the Rafael del Pino Foundation has been gathering a group of scientific experts that have aimed at selecting 10 cutting-edge technologies for the future in which Spain has a comparative advantage in scientific terms, and that has resulted in the INTEC 2021 Report, coordinated by the Rafael del Pino Chair, Professor Javier García, https://frdelpino.es/ciencia-y-sociedad/ and in the publication of the book "España a ciencia cierta" (Fundación Rafael del Pino, 2021).