What is “Deep Tech” and what are Deep Tech Ventures?

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Excecutive Summary

The objective of this paper is to integrate and synthetize the criteria for categorizing deep-tech ventures, given the considerable hype that has beset the use of this term in recent years and the proliferation of approaches to its delineation. This is especially important today given the risks of having blurry definitions for political purposes and for the design of clear policies and support programs. In the first stage, we propose defining deep tech as 'science-based technology solutions' associated with critical dimensions of uncertainty, a perspective that allows for the changing dynamics characteristic of a fast-changing technological landscape. In the second stage, we encapsulate five criteria that emerge from our uncertainty-based approaches and from the literature to define deep-tech *ventures*, as enterprises that are: 1) positioned at the scientific frontier, with long and uncertain R&D cycles, 2) building tangible, often regulated, products and processes, 3) linked to key ecosystem stakeholders, especially Higher Education Institutions, 4) problem oriented or mission-driven, and hence directed to the solution of public value failures, and 5) built through a dynamic de-risking cycle which recognizes the option space faced by founders and investors. With this approach we intend to offer a comprehensive framework for defining deep tech and deep-tech ventures, which is based not only on quantifiable economic criteria, but also on other qualitative and operational criteria that are appreciated by founders and their stakeholders.

Introduction

The term "deep tech" has emerged over the last years to distinguish a specific category of innovative solutions. If innovation is the match between problems (customer needs or opportunities) and solutions (technologies, business models etc), then deep tech is that part of the solution space based on breakthrough science and engineering. Thus, deep tech ventures are those whose innovative solution is grounded is science and technology. As such, deep tech ventures have "*the potential to dominate the future in many ways*"[1] but more importantly, have a variety of characteristics with respect to time, capital intensity and uncertainty that require new or adapted approaches to their founding, growth, and support.

When first coined, the term deep tech was intended to categorize *"startups in the life sciences, energy, clean technology, computer sciences, materials, and chemicals sectors"* (Chaturvedi, 2015). By now the expression is in more widespread use appearing in Crunchbase and Sifted among other popular media sites.[2] Some have used terms such as "tough tech" (see for example The Engine investment fund built by MIT)[3], and others have used terms such as "frontier tech" or "hard tech". But the term deep tech has stuck and as such provides a focused category for ventures within the wider category of "high tech". As important, it serves in distinction to digital tech (which is often more simply referred to as 'tech') and is a subset of innovation-driven enterprises.[4]

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[1] The term "deep-tech" was first coined in 2015 by Swati Chaturvedi, founder of Propel(x), the world's first platform dedicated to angel investing in deep-tech startups. (https://www.linkedin.com/pulse/so-what-exactly-deep-technology-swati-chaturvedi/)

[2] See for example https://news.crunchbase.com/venture/deep-tech-funding-investors-quantum-cruise/

[3] https://engine.xyz/

[4] For more on the distinction between SMEs and IDEs and specifically the role of deep-tech ventures as a subset of IDEs see Budden, Murray and Ukuku (2021) Differentiating Small Enterprises in the Innovation Economy: Start-ups,

In recent years, the use of the term deep tech has become the source of considerable hype (DealRoom, 2021). As has happened to other concepts[5], the notion of a deep tech venture risks being applied too broadly, thus losing its utility as a specific category of ventures separate from others. Indeed, if the term (and thus the ventures themselves) becomes too comingled with other concepts (e.g. high-tech firms, technology-based companies, knowledge-intensive enterprises, disruptive technologies, or even innovation-driven enterprises), there is growing confusion about equivalence, posing challenges for those designing and implementing clear policies or support programs intended to promote the founding and growth of deep tech ventures.[6] For example, the broader term innovation-driven enterprise (IDE) was coined by MIT researchers to distinguish ventures whose solution provided a source of competitive advantage and differentiation could be based on non-technological innovation (e.g. business model), on digital tech or on deep tech. Similarly, the notion of "technology-based company" (TBC) has been applied from a broad to a narrow perspective (Trenado and Huergo, 2007). The broadest application includes companies operating in high-technology industries even when their activity is based on "copycat" business models using existing technology and even externally developed technologies. The narrow application of the TBC concept can be considered close to deep tech and implies the development of novel technology solutions, although it is not completely equivalent, as deep tech has been importantly related to breakthrough or paradigm changing technological innovations grounded in scientific research.

To the extent that deep tech ventures continue to serve as a category for entrepreneurs, investors and policymakers as well as those running programs to support them, it is useful to provide clear criteria for its definition, and one that is useful to action-oriented stakeholders, and not simply to scholars. This will allow decision-makers to develop coherent and effective actions and policies for the promotion of this kind of venture building and for more coherent investment models (Portincaso, Gourevitch, De la Tour, Legris and Hammoud, 2021).

The objective of this note is thus to **integrate and synthesize the criteria for defining deep-tech ventures,** as emerging from relevant reports and approaches to the topic[7], and to offer a unified framework that includes not only more easily quantifiable economic criteria, but also other "vision-" and "operational-" criteria that qualify these ventures.

STAGE ONE: Defining deep-tech

Two main approaches have emerged in the literature to define the concept of deep tech: the *material approach*, based on the sector to which the technology belongs, and an *approach* based on

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new SMEs & other Growth Ventures. https://innovation.mit.edu/assets/BuddenMurrayUkuku_SME-IDE_WorkingPaper__Jan2021.pdf

[5] Chaturvedi stated that the term "high tech" has been applied to different categories of technology companies, although most current technology companies are "*built on business model innovation or offline to online business model transition using existing technology*" (Ibid).

[6] For example, deep-tech entrepreneurs in Spain identify weaknesses in public grants that are not suited to their needs, and believe that some public grants aim at "the future" (i.e. looking for disruptive solutions) while looking at the present (i.e. requiring indicators and accountancy rules designed for certain project results). Similarly, confusion about the concept poses challenges for private funding, which often does not differentiate between "p*aying for technologies developed by third parties … or developing your own differential technology*" (interview with a specialized deep-tech investor). See also Botelho, Fehder and Hochberg 2021for the policy importance of distinguishing different types of ventures (https://www.nber.org/papers/w28990)

[7] Extensive reports on the topic have been produced by Hellowtomorrow and Boston Consulting Group, which define some of the most relevant characteristics of deep tech (e.g. De la Tour et al., 2021, Portincaso et al. 2021, De la Tour et al. 2017).

microeconomic reasoning that places the notion of barriers to entry at the center of the definition (Hafied, 2022).

The **material approach** defines deep tech based on sectoral or product criteria (Hafied, 2022) and, hence, it does not properly reveal that the deep-tech character of a sector is not immutable. Indeed, a sector that is considered as located at the technological frontier today (e.g. materials, blockchain, drones, artificial intelligence, aerospace, robotics, biotech, quantum computing etc.) may no longer be considered as such tomorrow, once the underlying technology matures. To put it more starkly, "*there is no such thing as a deep technology*" (De la Tour, Portincaso, Goeldel, Chaudry, Tallec and Gourevitch, 2021) and, as in the case of the definition of "high-tech", an industry-based definition is not satisfactory as it does not include a dynamic element, so necessary in the current fast-changing technological landscape.

On the other hand, an alternative approach can be articulated around the presence of barriers to entry (Hafied, 2022)[8]. From this perspective, deep tech presents two types of barriers to entry: i) the **existence of a high level of information asymmetry**, and ii) the presence of a **high level of capital intensity** (Kolev, Haughey, Murray and Stern, 2022). These two barriers constitute a source of potential market failure, and hence lead to limited private actions (especially private sector investment) that justifies the corrective intervention on the part of the State or other specialized investors or venture capitalists driven by criteria in addition to market returns.

Information asymmetry is particularly related to the uncertain future returns of R&D and to the high failure rate of deep-tech projects. The uncertainty in deep tech turns out to be an essential element of what makes deep tech unique and as such serves as the center of our definition. It is shaped by several factors:

a) insufficient state of knowledge and non-linearity of the "innovation trajectory" (Dosi, 1988), which is made up of plateaus, feedback and at times exogenous or unanticipated breakthroughs – in other words, considerable technical risk (Azoulay, Fuchs, Goldstein and Kearney, 2019) leading to a lack of predictable outcomes [9];

b) existence of pronounced regulatory risk in terms of the regulatory pathway that a solution will need to follow, or the evidence that will need to be developed to demonstrate technical effectiveness in a reasonable and reliable fashion;

c) uncertain or insufficient market demand, especially in emerging markets or when the destination market has a scarce industrial fabric; and

d) uncertain scale up and production characteristics, meaning that, even if a technology works at scale, the ability to actually produce the solution (and build a supply chain to do so) reliably is fraught with uncertainty[10].

Taken together these four types of uncertainty result in several characteristics of deep tech projects. First, as noted by Kolev et al. (2022), these different types of uncertainty together mean that scientists

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[8] From an operative political experience perspective, the case of the French "Deep Tech Plan" is interesting, as it promoted an operational implementation of a hybrid definition of deep tech ventures during its dedicated plan, reconciling both the material and organic approaches Hafied, Goreichy and Roulleau (2021).

[9] In the biotech sector, for example, an MIT study showed that only 3.4% of oncology clinical trials conducted between 2000 and 2015 ended up obtaining marketing authorization from the FDA (Federal Drug Administration) (Wong, Siah and Lo, 2018).

[10] Scalability concerns tangible innovations, as intangible assets can be deployed more easily thanks to a marginal cost of production tending towards zero (Haskel and Westlake, 2017).

themselves are likely to have both private information but as importantly private beliefs about the value of their scientific ideas (particularly with regards to technical uncertainty). Second, the capital intensity required to resolve these categories of uncertainty will be high, and significantly higher than those typically associated with digital tech projects. Taken together high capital intensity and high levels of private information will generally lead to under-investment by a range of external parties because it is almost impossible for private investors to fully evaluate the future returns of deep technology projects. Noting that conventional valuation methods are inoperative for deep tech projects[11] (Hafied, 2019), the difficulties in evaluating deep-tech result in a risk of adverse selection (i.e. those who carry the project know more than the investors about its chances of success, and this may lead to bad projects managing to raise funds) and moral hazard (i.e. imprudent management of the funds raised by deep tech entrepreneurs) (Akerlof, 1970, Aghion, Dewatripont and Stein, 2005, Kolev et al., 2022).

It is these characteristics of deep tech projects (i.e. their associated uncertainty) that leads to under investment and information asymmetry rather than being a fundamental feature of deep tech per se. As a result, although the popularized notion of deep tech has been in many cases related to the selection of specific technologies, the economic literature leans towards a definition that is based on more generalizable characteristics of deep tech and towards microeconomic reasoning (Hafied, 2022), and emphasizes outcomes such as capital allocation. In this sense, it is more useful to emphasize deep tech as being associated with critical dimensions of uncertainty (and thus likely to change in its categorization of specific technologies over time) and associated market failures (Guimón, 2021).

STAGE TWO: Defining Deep Tech Ventures

First criteria: Positioned at the knowledge frontier with long and uncertain R&D cycles

Deep-tech ventures are built on scientific discoveries or engineering innovations, with a strong research base, and are based on "*solutions built around unique, protected or hard-to-reproduce technological or scientific advantages*" (De la Tour, Soussan, Harlé, Chevalier and Duportet, 2017). This means that deep tech ventures are a narrow subset of TBCs and a narrow set of IDEs, which:

a) are positioned at the scientific knowledge frontier (Storey and Tether, 1998), possess a technological competitive advantage (Trenado and Huergo, 2007) and differential technological capabilities,

b) are based on the exploitation of an invention or technological innovation (at the frontier) that carries important technological risks (Little, 1977), and

c) have a strong focus on R&D activities (Conforto and Amaral, 2016), with potentially long and costly R&D cycles to de-risk the technology breakthrough.

Therefore, these companies face uncertainty, high levels of technological and commercial risks (as they are related to yet-to-be-developed commercial applications), and complexity (Conforto and Amaral, 2016; Mewes and Broekel, 2022), and, as noted above, face a specific set of challenges, including access to

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[11] The analogical method based on comparison with peers is unsuitable because deep tech companies are often a first or early mover and by definition have no comparable. The discount cash-flow method does not work because deep tech projects have negative cash flows for so many years and the discount rate is difficult to evaluate. Binomial methods based on decision trees and statistical assumptions about R&D development are available, but these are complex and often too theoretical (Hafied, 2019).

financing[12],which are related to market failures that are well understood in the literature on R&D and innovation policy (Guimón, 2021).

Second criteria: Are building tangible, often regulated, products and processes

Deep tech ventures work at the knowledge frontier but their end goal is not to produce abstract knowledge. Instead, they develop mostly physical and tangible products often based around highly defensible intellectual property (IP) thus combining physical assets with intangible knowledge assets and know-how.[13]

As a consequence of their physical nature, the products and services of deep tech ventures must be built at scale and thus require significant expertise not only in science and technology, but also in engineering, the development of heavy industrialization processes and the configuration of complex supply chains. This makes deep tech ventures more difficult to scale and scaling often comes with complex certification and regulation (De la Tour et al, 2017). Moreover, these ventures require higher capital intensity.

Third criteria: Linkages to the ecosystem and especially Higher Education Institutions

Given the complexity of the task at hand and the deep scientific and engineering foundations needed, deep tech ventures are more likely to be born and grow at the center of an interconnected ecosystem (Budden and Murray 2019), especially Higher Education Institutions and research institutions (Hausmann, 2022). In fact, deep tech ventures often emerge from research organizations (especially universities) as "*it is impossible for two people in a garage to come up with a meaningful deep-tech innovation*" and thus rely on hundreds of universities and research labs (De la Tour et al., 2021). Indeed, the expression 'lab to market' is often used in association with deep tech ventures to emphasize the journey from the (academic) research lab.

Remaining close to those institutions is often essential to access the human capital and infrastructure that support the early stages of technical development (Budden and Murray, 2019). As they continue along their lifecycle and achieve their commercial results deep tech ventures need to engage with wider ecosystem stakeholders including governments and corporate partners for funding and sources of demand (customer contracts etc). In other words, these ventures are often more intensely affected by systemic failures (Guimón, 2021), particularly regarding the barriers for collaboration or associated frictions between the different key stakeholders of the ecosystem.

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[12] As deep-tech ventures have higher difficulties in accessing external financing, scales such as the technology readiness level (TRL), the method developed by NASA for estimating the maturity of different types of technologies, or the market readiness level have been widely applied for evaluating these types of ventures and their needs (Solberg and Brem, 2016). TRLs are based on a scale from 1 (stages of basic technology research in which basic principles have been observed) to 9 (most mature stages, where the actual system has been proven in operational environment or competitive manufacturing in the case of key enabling technologies; or in space).

[13] https://sifted.eu/articles/2022-deeptech-investors/

Fourth criteria: Problem oriented or Mission-driven ventures

Deep tech ventures can serve a wide range of different customers and end markets. That said, they are often mission-driven – meaning that they strive to make a difference in the world and solve important societal challenges. n fact, a survey launched by De la Tour et al. (2021) into 1277 deep tech companies showed that 97% of them considered themselves to be contributing to at least one sustainable development goal (SDG), specifically related to health and climate and sustainability challenges. As such, they are mission-driven in the broadest sense of often being focused on specific problems that are nested within grand challenges (Mazzucato and Penna, 2015; Hekkert, Janssen, Wesseling, and Negro, 2020) and, as such, constitute a critical vehicle for solving public value failures (Mazzucato 2015) in response to social challenges (Kuhlmann and Rip, 2018).

By most definitions, deep tech ventures thus materialize the path of “use inspired basic research” from the lab into impact on wider society (Stokes, 1997; Murray, 2002; Budden and Murray, 2019). This orientation should not be a surprise given the complexities, cost and time associated with building a deep tech venture. Indeed, it is an essential element of many (although not all) deep tech ventures given the role that a mission- or problem- orientation plays as an “essential vector to navigate complexity” (De la Tour et al., 2021) and a guiding purpose on a long and complex journey to impact.

Fifth criteria: Creation of an “option space” and a dynamic de-risking cycle

Deep tech ventures are characterized by significant advances in science and technology as well as engineering, thus creating an “option space” which is broader than a specific product or solution (Azoulay et al., 2019; De la Tour et al., 2021). To be successful, deep tech venture teams must simultaneously explore and understand customer needs (and the risks associated with meeting the specific technical needs of different customer segments) but also leave a range of options open. In other words, deep-tech startups avoid falling into “product myopia” or “falling in love” with a business-model or a specific solution (Pérez-Breva, 2017; Gans, Kearney, Scott, and Stern, 2020). Instead, deep tech ventures generate and preserve “optionality”, that is, the leverage of science and technology to address the widest possible set of problems (De la Tour et al., 2021), while also finding a path to profitable scale and scope.

From the perspective of both the team and the investors in a deep tech venture, effective leadership in a complex and uncertain environment is challenging. It requires dynamic learning-cycles to de-risk different paths, demonstrate progress and allow for an increase in certainty and value even before a product or service is commercialized at scale (Pérez-Breva, 2017). While allied in spirit to so-called ‘lean startup’ methodology (Blank, 2013) and sharing an emphasis on learning, the leadership approach (and capital/time allocation) within deep tech ventures is centrally focused on technical and scaling insights. Teams will iterate towards technical milestones along a technical path in consultation with customers more than they will iterate with a prototype in the hands of the customer to determine the exact set of desirable attributes. Teams emphasize the minimum viable pathway to demonstrate of product, production and regulatory success rather than a minimum viable product.

The following table offers a summary of the five criteria, with a suggestion of questions to use as a checklist of characteristics of deep tech ventures to be considered in analysis, assessments and decision-making.

Criteria			**Answer if Deep-tech**
1. Positioned at the knowledge frontier with long and uncertain R&D cycles	**R&D at the core**	Is the developed technology at the knowledge frontier? Is there a quest for fundamental understanding?	**Yes**
		Is technology at the core of the company's activity?	**Yes**
		Is the technology internally developed?	**Yes**
	Information asymmetry	Is there sufficient available knowledge about the future trajectory of the innovation/technology?	**No**
		Is there a high regulatory risk?	**Yes**
		Is there a certain market demand?	**No**
		Is it easy to evaluate future returns of investment?	**No**
2. Importantly related to tangible products and industrialization processes	**High capital intensity**	Are there high fixed launch and development costs?	**Yes**
		Is there a need for industrialization processes?	**Yes**
	Hard scalability and tangibility	Is the product easily scalable? Is the product mainly intangible?	**No**
3. Linkages to the ecosystem and especially Higher Education Institutions	**Needs of being close to the innovation ecosystem**	Does the venture require close links to other stakeholders of the ecosystem? (in particular HEI, risk capital, government, and industry)?	**Yes**
4. Problem orientation or Mission-driven ventures	**Problem orientation**	Is there a "consideration of use"? Is interest in utility and problem orientation at the core of the company? Is the definition of the problem the core element or the "essential vector to navigate complexity"?	**Yes**
5. Creation of an "option space" and a dynamic de-risking cycle	**Optionality**	Is there a convergence of different approaches (advanced science, engineering, design) and technologies in the company? Is the focus on creating an "option space" addressing the widest possible set of problems?	**Yes**
		Is the company obsessed with a specific product or solution?	**No**
	De-risking dynamic cycle	Does the company create dynamic learning cycles to de-risk development and commercialization?	**Yes**

Conclusions

Deep tech is considered important, not only for its potential for economic development, but for its power to create impactful solutions to important societal challenges: from health and energy security to peace, wellbeing, and prosperity. If deep tech is important for economic growth, then it should be clear how to draw boundaries around deep tech projects, and deep tech ventures in particular. To date, this has been challenging, as many different definitions of deep tech abound.

Our short note synthesizes the key aspects of the notion of deep tech and specifically the immutable characteristics associated with uncertainty and proposes five clear criteria to recognize the fundamental characteristics of deep tech ventures and the approach needed to their management and successful scaling: 1) positioned at the knowledge frontier with long and uncertain R&D cycles; 2) related to tangible products and industrialization processes; 3) linked to the ecosystem and especially to Higher Education Institutions; 4) problem oriented or mission-driven; 5) focused on the creation of an “option space” and a dynamic de-risking cycle. Taken together these criteria not only define the space of deep tech ventures and their close relation to market failures, systemic failures and public value failures, as analyzed by recent innovation policies, but also start to illuminate the likely challenges faced by teams and investors supporting their growth and scaling.

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