ÁREA TEMÁTICA:

EMPREENDEDORISMO, STARTUPS E INOVAÇÃO

TÍTULO DO ARTIGO:

CITIES AND DEEP-TECH STARTUPS: CONTRIBUTIONS FROM AN STOCHASTIC FRONTIER ANALYSIS

ABSTRACT
In recent years, the number of early-stage ventures based on deep technologies (e.g., artificial intelligence, big data, quantum computing, among others) has been growing. A deep-tech startup is a “company founded on a scientific discovery or meaningful engineering innovation” (CHATURVEDI, 2015, p. 1). The success of these startups is uncertain, as they require long/slow R&D cycles to transform technologies into suitable innovations for markets. For these reasons, studies show that these ventures are less attractive to venture capitalists. Deep-tech entrepreneurship is more concentrated in developed contexts. Studies on entrepreneurial cities focus on high-growth or business birth rates. So far, there are few studies on deep-tech startups from a city level perspective, i.e., which aim to reveal which factors drive or inhibit the creation of these startups. Therefore, the purpose of this article is to assess whether the resource endowment of cities influences the number of deep-tech startups. In this study, we apply a Stochastic Frontier Analysis (SFA) to a database composed of 68 cities, e.g., the San Francisco Bay Area, São Paulo, and Shenzhen, among others. To create our database, we collect data about deep-tech startups from Crunchbase and data about entrepreneurial cities' resources and actors, we collect data from Research Organization Registry, Crunchbase, and StartupBlink. Our results showed the concentration of Education and Research Institutions, Business Incubators, Accelerators, and Venture Capitalists Investors are good predictors of entrepreneurial activity based on deep technology.

Keywords: Crunchbase. Regional entrepreneurship. Production Possibility Frontier.

RESUMO
Nos últimos anos, o número de empreendimentos em estágio inicial baseados em tecnologias profundas (por exemplo, inteligência artificial, big data, computação quântica, entre outros) vem crescendo. Uma startup de tecnologia profunda é uma “empresa fundada em uma descoberta científica ou inovação de engenharia significativa” (CHATURVEDI, 2015, p. 1). O sucesso dessas startups é incerto, pois exigem ciclos longos/lentos de P&D para transformar tecnologias em inovações adequadas aos mercados. Por essas razões, estudos mostram que esses empreendimentos são menos atraentes para os capitalistas de risco. O empreendedorismo de tecnologia profunda está mais concentrado em contextos desenvolvidos. Estudos sobre cidades empreendedoras concentram-se em taxas de alto crescimento ou natalidade de empresas. Até o momento, existem poucos estudos sobre deep-tech startups em nível da cidade, i.e., que visam revelar quais fatores impulsionam ou inibem a criação dessas startups. Portanto, o objetivo deste artigo é avaliar se a dotação de recursos das cidades influencia o número de startups de tecnologia profunda. Neste estudo, aplicamos uma Stochastic Frontier Analysis (SFA) a um banco de dados composto por 68 cidades, e.g., a área da baía de São Francisco, São Paulo e Shenzhen, entre outras. Para criar nosso banco de dados, coletamos dados sobre startups de tecnologia profunda de Crunchbase e dados sobre recursos e atores de cidades empreendedoras, coletamos dados de Research Organization Registry, Crunchbase e StartupBlink. Nossos resultados mostraram a concentração de Instituições de Ensino e Pesquisa, Incubadoras de Empresas, Aceleradoras e Venture Capitalists Investidores são bons preditores de atividade empreendedora baseada em tecnologia profunda.

Palavras-chave: Crunchbase. Empreendedorismo Regional. Fronteira das Possibilidades de Produção.

1 INTRODUCTION

One of the first authors to introduce the phrase "entrepreneurial city" to describe the shift in the thinking of local administration from "managerialism to entrepreneurship" was Harvey (1989) in the 1980s. Based on Spilling's (1996) entrepreneurial systems, Van De Ven's (1993) industrial infrastructure for entrepreneurship, and the idea of a business environment, Cohen (2006) developed the concept of entrepreneurial ecosystems (EE). However, it wasn't until the 2010s that the concept of EE gained popularity, mainly because of Isenberg's (2010) landmark work and the startup communities described by Feld (2012). Studies on EE (AUDRETSCH et al., 2012; AUTIO et al., 2014; SZERB et al., 2014) also indicated the necessity of studying entrepreneurship at the local level, as local factors affect people's decisions, in addition, until then, there were few studies on the influence of local context on entrepreneurial activity.

This shift in the emphasis of EE studies is mostly attributable to the fact that entrepreneurship rates, performance, and effect differ between regions and/or cities within the same nation (AUTIO et al., 2014). According to research, there are disparities between metropolitan areas/large cities and small cities in terms of the dynamism of entrepreneurship depending on population density (BOSMA; STERNBERG, 2014; ROUNDY, 2017). The proximity to large metropolitan areas is one of the determinants of entrepreneurial activity at the local/regional level, according to other studies (LONG; ZHENG; QIAN, 2022; SCHNELL et al., 2017), which also demonstrate that even small cities can present innovative entrepreneurial activity if they have the necessary conditions to boost entrepreneurship. The differences between the number of startups and the growth of innovative ventures within the same country (AUDRETSCH et al., 2016; BOSMA, 2009; FRITSCH; STOREY, 2014; STERNBERG, 2009) occur because entrepreneurial performance is moderated by the complex and systemic interactions between entrepreneurs and their context (AUDRETSCH; KEILBACH; LEHMANN, 2006; LEVIE; AUTIO, 2011).

Despite the development of studies that emphasize the role of local contexts on entrepreneurial performance, most studies examine the differences between cities located in the US, European Union, and China, as well as the prevalence of startups and/or business birth rates. Regarding deep technology entrepreneurship, i.e., "companies founded on a scientific discovery or meaningful engineering innovation" (CHATURVEDI, 2015, p. 1), which refers to startups based on emerging/deep technologies (e.g., Artificial Intelligence, Big Data, robotics, etc.) a source of competitive advantage (SIOTA; PRATS, 2021). Because it is a concept of entrepreneurship associated with emerging technologies, there are still few studies on the factors that can boost or inhibit the creation of deep-tech startups (DIONISIO et al., 2023). In addition, so far, no study addresses the factors that affect deep-tech entrepreneurship at the city level. Thus, this research aims to answer the following questions: *How do entrepreneurial cities perform in terms of creating deep-tech ventures and what factors affect this entrepreneurial activity?*

The purpose of this research is twofold. First, we aim to identify which resource endowments affect deep-tech entrepreneurship. Secondly, we seek to assess how entrepreneurial ecosystems at the city level perform regarding resource allocation to new venture creation. To achieve these goals, we apply Stochastic Frontier Analysis (SFA) an approach to assess the performance of decision-making units - DMUs (e.g., firms, cities, countries etc.). SFA is one of the most used parametric techniques, taking statistical disturbances into account (BOGETOFT, 2012). The frontier form of the function must be considered. Stochastic variables and external causes, such as investments' attractiveness, availability of skilled labor, and endowment resources, are known as statistical disturbances or noise terms (AGHLMAND et al., 2022). This method is an econometric tool that shows the impact of the noise term on efficiency, which is outside the control of DMUs and identifies divergence from the best performance frontier (BOGETOFT, 2012). This feature separates the divergence from the frontier into two parts: random error and inefficiency. A better definition of inefficiency based on economic theory is provided by this method, which estimates the production function as the maximum output that can be generated from a set of production factors. If the rate of production factors and production is a random process, the SFA is applicable (BOGETOFT; OTTO, 2011).

The application of SFA in the context of entrepreneurial ecosystems - regardless of the level of analysis, city, region, and country - is particularly relevant, as the success of an enterprise depends on deterministic and random (stochastic) factors. Among the deterministic factors, we can highlight the skills of entrepreneurs, the availability of labor, and financial resources, among others (MICHELACCI; SCHIVARDI, 2020; SÁNCHEZ, 2011). As stochastic factors, we can consider the acceptance of innovation by consumers, macroeconomic conditions, and failures in R&D processes, among others (CLERCQ; BOWEN, 2008; FELDMAN, 2001; FRITSCH; STOREY, 2014). Because deep-tech ventures are characterized by uncertainty regarding the demand for their solution offered, by the long/slow R&D cycles and by the difficulty for investors to understand the business model of a deep technology venture (DIFFERENT FUNDS, 2020; SIOTA; PRATS, 2021). We argue that the success of a startup depends on both deterministic and random factors, a fact that can explain the variation in entrepreneurial activity in cities of the same country (see AUTIO et al., 2014).

2 ENTREPRENEURIAL CITIES

The early 1990s and late 1980s saw the first studies on entrepreneurial cities. However, the term "entrepreneurial city" utilized in these studies to indicate how local governments participated in the planning of initiatives that improved economic development (HARVEY, 1989; SBRAGIA, 1996)pertaining to municipal administrations' initiatives to support urban regeneration (FRIEDEN; SAGALYN, 1989; ROBERTS; SCHEIN, 1993). Studies from the 2000s describe both the role of cities in promoting innovative activities (JESSOP; SUM, 2000) and the so-called “municipal capitalism”, which was based on the involvement of public administration in the promotion of economic activities of any nature, from industrial area projects to sports complexes (CHAPIN, 2002). Since 2010s, we observe the increasing in popularity of the concept of entrepreneurial ecosystems (EE) and their intrinsic link with the socio-economic factors of cities and/or regions (see BOSMA; STERNBERG, 2014; FELD, 2012; FLORIDA; ADLER; MELLANDER, 2017; ISENBERG, 2010). The most recent studies (CAVALLO et al., 2020; COLOMBELLI; QUATRARO, 2018; LIU; QIAN; HAYNES, 2021; LONG; ZHENG; QIAN, 2022; ROUNDY, 2017) on entrepreneurial cities began to use the EEs approach to assess whether the factors and resources available in a city influenced positively entrepreneurial activity.

Although many studies on entrepreneurial cities emphasize urban density and consequently look at patterns of entrepreneurship in metropolitan areas (BOSMA; STERNBERG, 2014), there are studies that seek to clarify the causal configurations of entrepreneurship in other areas. For example, Liu *et al*. (2021) examined the spatial patterns of high-tech startup creation in microregions of the United States. The authors identified that entrepreneurship in small cities is influenced by population growth, the presence of small business and natural amenities, as well as human capital and creative knowledge, in addition to proximity to large metropolitan areas. Similarly, Long *et al*. (2022) analyzed the causal factors of entrepreneurship in peripheral regions of China and identified the influence of the macroeconomic context and industrial specialization on entrepreneurship.

2.1 Drivers of entrepreneurial cities and hypothesis formulation

Education and Research Institutions (ERI) can contribute to the entrepreneurial ecosystem in two ways, the first is by providing qualified human capital to conduct research, development, and innovation activities, and the second is by creating new knowledge that can lead to economic opportunities for entrepreneurs (QIAN; ÁCS; STOUGH, 2015). In addition, the infrastructure of the ERIs can provide the necessary resources (MILLER; ÁCS, 2017) and knowledge for students and/or entrepreneurs to develop innovative entrepreneurial projects (COLOMBO; PIVA, 2020). There is evidence in the literature that the presence of ERIs has a positive impact on entrepreneurship ecosystems, human capital produces innovations and universities produce local impacts (RUCKER SCHAEFFER; FISCHER; QUEIROZ, 2018), in the form of generating spin-offs (CAPONE; MALERBA; ORSENIGO, 2019; PROKOP, 2021), a fact that explains that the presence of innovative enterprises in regions close to universities or ventures created by university students and/or faculty (AUDRETSCH; LEHMANN; WARNING, 2005). Hence:

H1: A region’s deep technological entrepreneurial activity is positively related to the number of Education and Research Institutions (ERIs) in the region.

Large established companies are recognized by the literature of entrepreneurship and geography of innovation as anchor organizations that attract skilled workers and intermediary industries (FELDMAN, 2003; SPIGEL; VINODRAI, 2020), often correlated, increasing the value chain size, and leading to industrial specialization (HERNANDEZ; ATIENZA; MODREGO, 2022). There is evidence that startups that collaborate with established companies have opportunities to scale faster (BĂRBULESCU; CONSTANTIN, 2019). Therefore, cities that host anchor firms can attract or stimulate the creation of companies that can act as suppliers to incumbents (XUE; KLEIN, 2010). In addition, former employees of incumbents may create companies to provide services and/or products to their former employers (SZERB et al., 2015). Thus:

H2: A region’s deep technological entrepreneurial activity is positively related to the number of Anchor Firms in the region.

Co-working spaces (CWS) allow entrepreneurs to share office spaces with other entrepreneurs and create relationship networks (BOUNCKEN; REUSCHL, 2018). These spaces can facilitate knowledge and information flows, as well as share resources and establish partnerships between entrepreneurs (BOUNCKEN; ASLAM, 2019). Therefore, CWS can provide the necessary infrastructure and network for early-stage entrepreneurs to launch their businesses (CAVALLO; GHEZZI; SANASI, 2021). Hence:

H3: A region’s deep technological entrepreneurial activity is positively related to the number of co-working spaces in the region.

Business incubators (BI) and accelerators (AC) are recognized by the literature as organizations that support early-stage entrepreneurial activity (CAVALLO; GHEZZI; SANASI, 2021). A BI is an organization whose function is to support the development and growth of startups, by providing physical infrastructure, guidance, networking, training, validation of ideas, and visibility of products and/or services (LI et al., 2020). Some BI, especially those linked to universities, provide technology transfer (BLANK, 2021), while others can help entrepreneurs in their search for funding (CAVALLO; GHEZZI; SANASI, 2021). Similarly, an AC is an organization that provides mentoring and a support network to entrepreneurs to increase their ability to attract investment. In addition, accelerators help entrepreneurs reshape their innovations to make them more viable for consumers (DRORI; WRIGHT, 2018). There is evidence in the literature that both BI and AC drive the creation of startups in the regions where they are located (BLANK, 2021; BLIEMEL et al., 2019; DEL BOSCO et al., 2021). This suggests the following hypotheses:

H4: A region's deep technological entrepreneurial activity is positively related to the number of business incubators in the region.

H5: A region's deep technological entrepreneurial activity is positively related to the number of accelerators in the region.

Financial resources are essential for entrepreneurs, as most of them, especially innovators, lack the initial capital needed to start their businesses (KENNEY; ZYSMAN, 2019; URBINATI et al., 2019). These resources can be provided by venture capitalists, business angel investors, and investment banks (CAVALLO et al., 2019). In addition to providing financial resources, investors can offer expertise to early-stage entrepreneurs (CAVALLO; GHEZZI; SANASI, 2021). The entrepreneurial ecosystems' literature suggests that the presence of investors in a region is an attractive force for entrepreneurs and incumbents, who settle in a region to access available financial resources (SPIGEL; HARRISON, 2018). This suggests the following hypotheses:

H6: A region's deep technological entrepreneurial activity is positively related to the number of venture capitalists' headquarters in a region.

H7: A region's deep technological entrepreneurial activity is positively related to the number of business angels' headquarters in a region.

H8: A region's deep technological entrepreneurial activity is positively related to the number of investment banks in the region.

3 RESEARCH DESIGN

3.1 Data and sample

We select entrepreneurial cities based on ecosystems ranking provided by StartupBlink 2022 report. Our initial sample is composited by the ranking of the 100 best entrepreneurial cities. However, we restricted our database to cities with actively deep-tech startups. Then, we identified 68 cities. Our dependent variable (output) is the deep-tech startups, whose data was collected from the search engine of Crunchbase website (see www.crunchbase.com/discover/organization.companies). We selected deep-tech startups based on studies by the IESE Business School of Navarra (SIOTA; PRATS, 2021) and Startup Genome (2020) that highlight deep technology companies those based on AgTech, advanced materials, artificial intelligence, Big Data, biotechnology, blockchain, drones and robotics, and quantum computing. To ensure that we only choose businesses that are in a similar stage of growth, we have set the five-year period. The time limit is particularly important since it enables us to choose only start-ups with cutting-edge ideas.

Table 1 - Definition of variables and sources

Variable	ID	Description	Source
Deep-tech startups	DTS	Number of deep tech-based startups founded between 2017-2022	Crunchbase
Education and Research Institutions	ERI	Number of education and research institutions based in the city	Research Organization Registry
Anchor firms	AF	Number of technology firms with more than 1000 employees located in the city	Crunchbase
Co-working spaces	CWS	Number of coworking spaces located in the city	StartupBlink
Accelerators	AC	Number of accelerators located in the city	StartupBlink
Business incubators	BI	Number of incubators located in the city	Crunchbase
Venture capitalists	VC	Number of venture capitalists headquartered in the city.	Crunchbase
Business Angels	BA	Number of angel investors and groups of angel investors located in the city.	Crunchbase
Investment banks	IB	Number of investment banks headquartered in the city	Crunchbase

Source: Elaborated by the Authors

The independent variables were selected based on the study by Cavallo, Ghezzi, and Sanasi (2021) who suggest that an entrepreneurial ecosystem at the city level is composed of education and research institutions, co-working spaces, accelerators, business incubators, venture capitalists, business angels and investment banks. Data for the independent variables (inputs) were collected from different databases, such as Crunchbase, Research Organization Registry, and StartupBlink.

3.2 Stochastic Frontier Analysis (SFA)

In this research, we applied SFA to evaluate the technical efficiency of the production units. SFA is a powerful statistical technique for estimating the efficiency of units relative to an efficient production frontier, considering both observable and unobservable factors (BOGETOFT, 2012). To perform the efficiency analysis, we apply the SFA using the "Frontier" package in the R software. The SFA allows us to model the observed output as a combination of stochastic technical efficiency and random errors. The SFA model used is defined as:

$$\log(DTS) \sim \beta_0 + \beta_1 * \log(ERI) + \beta_2 * \log(AF) + \beta_3 * \log(CWS) + \beta_4 * \log(BI) + \beta_5 * \log(AC) + \beta_6 * \log(VC) + \beta_7 * \log(BA) + \beta_8 * \log(IB) + u$$

Where:

- log(DTS) is the logarithm of the dependent variable (DTS).
- log(ERI), log(AF), log(CWS), log(BI), log(AC), log(VC), log(BA), log(IB) are the logarithms of the independent variables.
- u is the random error term that incorporates unobserved factors.

We used the Maximum Likelihood Estimation (MLE) method to estimate the parameters of the SFA model. The MLE seeks to find the values of the parameters that maximize the probability of observing the real data, given the characteristics of the model. These parameter estimates will provide us with insights into how independent variables affect the production and technical efficiency of the entrepreneurial cities (BOGETOFT; OTTO, 2011).

4 RESULTS AND DISCUSSIONS

4.1 Empirical findings

Table 2 shows the results of the stochastic frontier analysis using the likelihood method. Four variables (ERI, AC, BI, and VC) had positive estimated coefficients and statistical significance at the p level. Therefore, there is evidence of a causal relationship between these variables and deep-tech entrepreneurship. Hence, hypotheses H1, H4, H5, and H6.

Table 2 - Estimation of Stochastic Frontier from the maximum likelihood method

Dependent variable: DTS		Coefficient	Std. error	z-value	p-value	Hypothesis	Supported
Intercept	β_0	2.582	0.396	6.511	0.000***		
log(ERI)	β_1	0.158	0.078	2.016	0.043**	H1	**Yes**
log(AF)	β_2	0.004	0.106	0.041	0.966 (ns)	H2	No
log(CWS)	β_3	-0.139	0.092	-1.513	0.130 (ns)	H3	No
log(BI)	β_4	0.243	0.066	3.652	0.000***	H4	**Yes**
log(AC)	β_5	0.187	0.071	2.622	0.008***	H5	**Yes**
log(VC)	β_6	0.430	0.069	6.205	0.000***	H6	**Yes**
log(BA)	β_7	0.079	0.058	1.355	0.175 (ns)	H7	No
log(IB)	β_8	-0.065	0.070	-0.936	0.348 (ns)	H8	No
Sigma-square	σ^2	0.251	0.085	2.932	0.003***		
Gamma	γ	0.823	0.160	5.120	0.000***		
Log likelihood		-18.74					

Notes:
ns = non-significant. ** = significant at 5% ($p > 0.05$). *** = significant at 1% ($p > 0.01$)

Source: Elaborated by the Authors

AF and BA present positive coefficients, suggesting that the presence of these entities improves the number of deep tech ventures, we did not identify statistical significance, therefore, these variables cannot be considered relevant for deep tech startups. tech. Thus, hypotheses H2 and H7 are not supported.

CWS and IB showed negative coefficients together with non-significant p-values. Therefore, there is no evidence that these entities affect deep-tech entrepreneurship. Hence, hypotheses H3 and H8 are not supported.

Table 3 displays the level of efficiency of each entrepreneurial ecosystem. Scores closer to 1.0 indicate an efficient ecosystem. On the other hand, scores much higher than 1.0 show entrepreneurial ecosystems far from the possibility production frontier, therefore, inefficient ecosystems. Our results show that the ecosystems nearest to the possibility production frontier are Tel Aviv (1.112), Pune (1.126), Oxford (1.142), San Diego (1.152), Greater Miami Area (1.162), Kitchener Waterloo (1.175), London (1.179), Dubai (1.186), Singapore (1.186), Washington DC Area (1.195) and Zurich (1.195).

In addition to these cities, other ecosystems with a high number of deep-tech startups and resources and support infrastructure are near to the production possibilities frontier, notably San Francisco Bay Area (1.202), Amsterdam (1.208), Greater Boston Area (1.216), Greater Seattle Area (1.281), and New York (1.296). The San Francisco Bay Area has the largest number of deep-tech startups. However, from an efficiency perspective, this ecosystem shows a lower efficiency score than Tel Aviv, this is because the Israeli city, even with few resources available to entrepreneurs, has a high generation of deep technology ventures.

Table 3 – Efficiency of entrepreneurial cities

Rank	City	Efficiency	Rank	City	Efficiency
1	Tel Aviv	1.112	35	Raleigh Durham	1.333
2	Pune	1.126	36	Bangkok	1.333
3	Oxford	1.142	37	Hamburg	1.336
4	San Diego	1.152	38	Atlanta	1.336
5	Greater Miami Area	1.162	39	São Paulo	1.348
6	Kitchener Waterloo	1.175	40	Vienna	1.351
7	London	1.179	41	Dallas-Forth Worth Area	1.359
8	Dubai	1.186	42	Istanbul	1.372
9	Singapore City	1.186	43	Philadelphia	1.379
10	Washington DC Area	1.195	44	Baltimore	1.401
11	Zurich	1.195	45	Bueno Aires	1.405
12	Hyderabad	1.200	46	Stockholm	1.410
13	San Francisco Bay Area	1.202	47	Hangzhou	1.419
14	Amsterdam	1.208	48	Greater Los Angeles Area	1.428
15	Greater Boston Area	1.216	49	Santiago	1.431
16	Toronto	1.224	50	Shanghai	1.435
17	Seoul	1.236	51	Tokyo-Yokohama Area	1.441
18	Bangalore	1.251	52	Paris	1.448
19	Munich	1.254	53	Denver	1.481
20	Vancouver	1.258	54	Bogota	1.484
21	Tampa Bay Area	1.261	55	Madrid	1.505
22	Houston	1.266	56	Chicago Area	1.521
23	Austin	1.268	57	Dublin	1.528
24	Lagos	1.276	58	Beijing	1.565
25	Greater Seattle Area	1.281	59	Kuala Lumpur	1.575
26	Sydney	1.286	60	Pittsburgh	1.606
27	Shenzhen	1.292	61	Prague	1.611
28	New York	1.296	62	Oslo	1.681
29	Berlin	1.297	63	Montreal	1.691
30	Copenhagen	1.298	64	Mexico City	1.751
31	Hong Kong	1.311	65	Salt Lake City - Provo Area	1.783
32	Milan	1.312	66	Jakarta	1.798
33	Warsaw	1.319	67	Mumbai	1.831
34	Barcelona	1.330	68	Moscow	2.638

Source: Elaborated by the Authors

Table 3 also displays the entrepreneurial ecosystems furthest from the production possibilities frontier are Moscow (2.638), Mumbai (1.831), Jakarta (1.798), Salt Lake City – Provo Area (1.783), Mexico City (1.751), Montreal (1.691), Oslo (1,681), Prague (1.611), Pittsburgh (1.606), Kuala Lumpur (1.575), Beijing (1.565), Dublin (1.528), Chicago Area (1.521), Madrid (1.505).

Moscow shows a high inefficiency score compared to other ecosystems. Compared to Tel Aviv, Moscow ties in terms of number of incubators and loses in terms of venture capitalists. The Russian city surpasses the Israeli one in terms of the number of education and research institutions, and accelerators. However, it has a low prevalence of deep-tech startups. From an efficiency perspective, Moscow has available resources and institutions to support entrepreneurs. However, it fails to generate significant results in terms of deep-tech entrepreneurship.

4.2 Discussions

Our research sought to identify resources which affect deep-tech entrepreneurship in entrepreneurial cities. Our results are in line with the literature, which shows that the presence of ERI creates positive effects in a region in terms of the creation of new innovative ventures (AUDRETSCH; LEHMANN; WARNING, 2005; CAPONE; MALERBA; ORSENIGO, 2019; PROKOP, 2021; RUCKER SCHAEFFER; FISCHER; QUEIROZ, 2018). Thus, a concentration of ERIs in one region results in an increased rate of deep-tech startups. Regarding entrepreneurship support organizations, our results are in line with the entrepreneurship literature, which shows that both incubators and accelerators are entities that help create new businesses (BLANK, 2021; BLIEMEL et al., 2019; DEL BOSCO et al., 2021; LI et al., 2020). Our results show that a high number of incubators and accelerators increases deep-tech startups.

Studies indicate that the availability of financial resources is factors that contribute to the growth of entrepreneurial firms. These resources may be provided by VC, BA, and IB. The literature indicates that the presence of investors in an entrepreneurial ecosystem promotes the creation of new businesses (SPIGEL, 2017; SPIGEL; HARRISON, 2018; SPIGEL; VINODRAI, 2020). Our results are partially in agreement with the literature. We identified that the presence of venture capitalists positively affects the number of deep-tech ventures (CAVALLO et al., 2019; MASON; COOPER; HARRISON, 2002). However, they are at odds in terms of business angels and investment banks (CAVALLO et al., 2019; CAVALLO; GHEZZI; SANASI, 2021; ISENBERG, 2010; MASON; HARRISON, 2008), as the results show that BA do not influence deep-tech entrepreneurship. As for IB, we did not identify a positive coefficient and a causal relationship. This fact indicates that banks do not affect the number of entrepreneurial startups.

Our research also analyzed the effects of the concentration of AF and CWS on entrepreneurial activity. Some studies (FELDMAN, 2003; HERNANDEZ; ATIENZA; MODREGO, 2022; SPIGEL; VINODRAI, 2020) on entrepreneurship show that regions that concentrate on large established companies indirectly promote entrepreneurship, as new companies can act as intermediaries and/or service providers for incumbents (SZERB et al., 2015; XUE; KLEIN, 2010). Our results disagree with the literature, as we did not identify a cause-and-effect relationship between AF and deep-tech startups. Regarding CWS, we also did not identify the influence of these organizations on deep-tech entrepreneurship. Thus, this finding is at odds with previous studies on the effects of CWS on the creation of new businesses (BOUNCKEN; ASLAM, 2019; BOUNCKEN; REUSCHL, 2018).

After evaluating the factors that affect deep-tech entrepreneurship, we performed an efficiency analysis using the SFA approach using Shepard-type efficiency, i.e., oriented to maximizing results. We identified the most efficient entrepreneurial cities are Tel Aviv, Pune, and Oxford. Compared to the San Francisco Bay Area, these cities have fewer organizations/actors that support entrepreneurship and a lower prevalence of deep-tech startups. However, they are closer to the production possibility frontier, as even with few resources they manage to significantly stimulate deep-tech entrepreneurship. Compared to other entrepreneurial cities like Boston and New York, these three cities represent a group that has very limited resources to drive entrepreneurship. On the other hand, entrepreneurial cities with abundant resources to create, develop and maintain adequate infrastructure to drive deep-tech entrepreneurship showed low returns in terms of efficiency.

The results of the efficiency analysis show that it is not necessary to seek to emulate the San Francisco Area to encourage entrepreneurship. Cities with few resources from entrepreneurial ecosystems can show impressive results in terms of creating deep-tech startups. Therefore, through the construction of an efficiency ranking, this research allows identifying which efficiency references can be observed to create entrepreneurship policies based on high rates of efficiency in terms of generating startups.

In this sense, this research advances studies that examine whether a factor affects the prevalence of deep-tech startups, as well as studies that seek to assess entrepreneurial cities performance using an efficiency approach. In this research, we also show that even if a city has a high number of deep-tech startups, it is not necessarily an efficient city in terms of producing entrepreneurial startups. Even cities with few resources can reach the production possibility frontier if they allocate resources appropriately to generate startups.

In addition, using a stochastic approach to assess the performance of entrepreneurial cities may be more appropriate than using techniques such as Data Envelopment Analysis (DEA), as deep-tech entrepreneurship is an activity shrouded in uncertainty, involving long/slow R&D cycles to transform an emerging/deep technology into a marketable one (DEALROOM, 2021; DIFFERENT FUNDS, 2020; GIGLER, 2018; SIOTA; PRATS, 2021). In this sense, deep-tech entrepreneurship is an activity related to deterministic elements and random (stochastic) phenomena that go beyond the control of cities and entrepreneurs. Thus, the SFA, an econometric technique, allows for assessing the ability of cities to generate deep technology ventures, considering both entrepreneurship production factors and random incidents (BOGETOFT; OTTO, 2011).

5 FINAL REMARKS

Entrepreneurship is not just the result of the entrepreneurs' competencies but also receives influences from resources endowments and contextual actors, especially those available and/or headquartered in cities and/or urban areas. In this sense, a city normally presents the characteristics of an EE, i.e., the concentration of universities and higher education institutions, business incubators and accelerators, and investors etc. The availability of these institutions and organizations and their interactions with individuals can boost entrepreneurial activity. Therefore, a city can be considered an EE, as it provides resources that stimulate entrepreneurship.

In this study, we evaluate whether the availability of resources and actors headquartered in cities affects deep-tech entrepreneurship. To do so, we use a stochastic frontier method (SFA), which allows us to identify the variables that affect entrepreneurial activity and cities' efficiency in terms of generating deep-tech startups. This study has relevant implications for academics and policymakers. From an academic perspective, our results contribute to previous studies of the causal relationship between resources present in cities and the level of entrepreneurial activity. Furthermore, the focus on deep-tech startups makes this one of the first studies to assess which city settings affect this type of entrepreneurial activity. Implications for policymakers are associated with applying an efficiency approach. In this study, we show that cities traditionally considered benchmarks for entrepreneurship such as the San Francisco Bay Area are relatively far from the production possibilities frontier. Furthermore, we found that cities with few resources dedicated to entrepreneurs achieved higher levels of efficiency. Based on these results, we recommend that policymakers not only formulate policies based on observation of policies implemented in traditional entrepreneurial cities, such as the San Francisco Bay Area but also look at the policies adopted by efficient cities in terms of venture generation. This observation is particularly relevant for cities with limited resources to invest in strengthening their entrepreneurial ecosystem.

These findings do not go without limitations. First, the measure of deep-tech entrepreneurship can hide significant qualitative differences in the content of entrepreneurial activities and related impacts on the socioeconomic environment (HENREKSON; SANANDAJI, 2019). Second, our study was limited to assessing the influence of actors and organizations inherent in entrepreneurial cities, we did not consider the influence of moderating factors such as entrepreneurial culture and the specific economic conditions of each city. Third, although we collected data from active startups between 2017 to 2022, we did not assess the evolution of entrepreneurial cities over the years. In this way, further research is needed to address socioeconomic aspects and evolutionary traits of cities' efficiency performance observed over time. These concerns must be advanced in both empirical and theoretical terms because of the entrepreneurial ecosystem concept's policy attractiveness and the effects of related activity.

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