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The spatial dimension of productivity

Connecting the dots across industries, firms and places

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This working paper offers a synthesis of the current knowledge on the determinants of productivity. It carefully reviews both “spatial” (e.g. agglomerations, infrastructure, geography) and “aspatial” (e.g. human capital, labour regulations, industry-level innovation and dynamism) productivity drivers and demonstrates how the underlying spatial dynamics behind the latter group makes all productivity determinants “spatial” in nature. The paper demonstrates that productivity is inherently a spatial phenomenon and its understanding without a local/regional dimension is incomplete.

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Keywords: spatial productivity, productivity growth, local development, cities, regions, industries, firms, places

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Foreword

Current productivity discourse, both in academia and policy-making, predominantly revolves around national and sectoral (or industry-level) productivity determinants. From international comparisons, we know a great deal about the aggregate drivers of productivity growth. We know relatively little about the role played by places and regions in defining their own productivity performance.

Due to their general scope, current national policies based on aggregate research are unlikely to effectively stimulate regional productivity growth and to decrease interregional inequality by leveraging regional and local assets. To devise successful subnational and place-based policies, a deeper understanding of the spatial dimension of productivity is needed. The urgency of such knowledge further increases as the global megatrends affect places along the urban-rural continuum differently.

The Spatial Productivity Lab (SPL) at the OECD Trento Centre for Local Development, which is an integral part of the Centre for Entrepreneurship, SMEs, Regions and Cities, is a dedicated research laboratory that generates and disseminates knowledge on the complex ways regional and local processes are linked to productivity performance at the subnational level. The SPL works with local and global partners to address the challenges faced by regions, cities and rural areas in supporting and stimulating their growth. The work explores the impact of agglomerated economies and the urban-rural linkages, the mechanisms of regional productivity catching-up and the role of regional authorities in promoting the bottom-up approaches to productivity improvement.

Based on its research and analyses, the SPL is able to help with design and implementation of efficient regional and local policies that facilitate productivity growth, creation of better jobs and increased general well-being with no places left behind.

This working paper is the first in a series of outputs by the Spatial Productivity Lab. It identifies the main productivity drivers and sets the ground for the future SPL research work, which will explore each of them in greater detail and across various contexts to generate timely insights for effective place-based policies.

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Executive summary

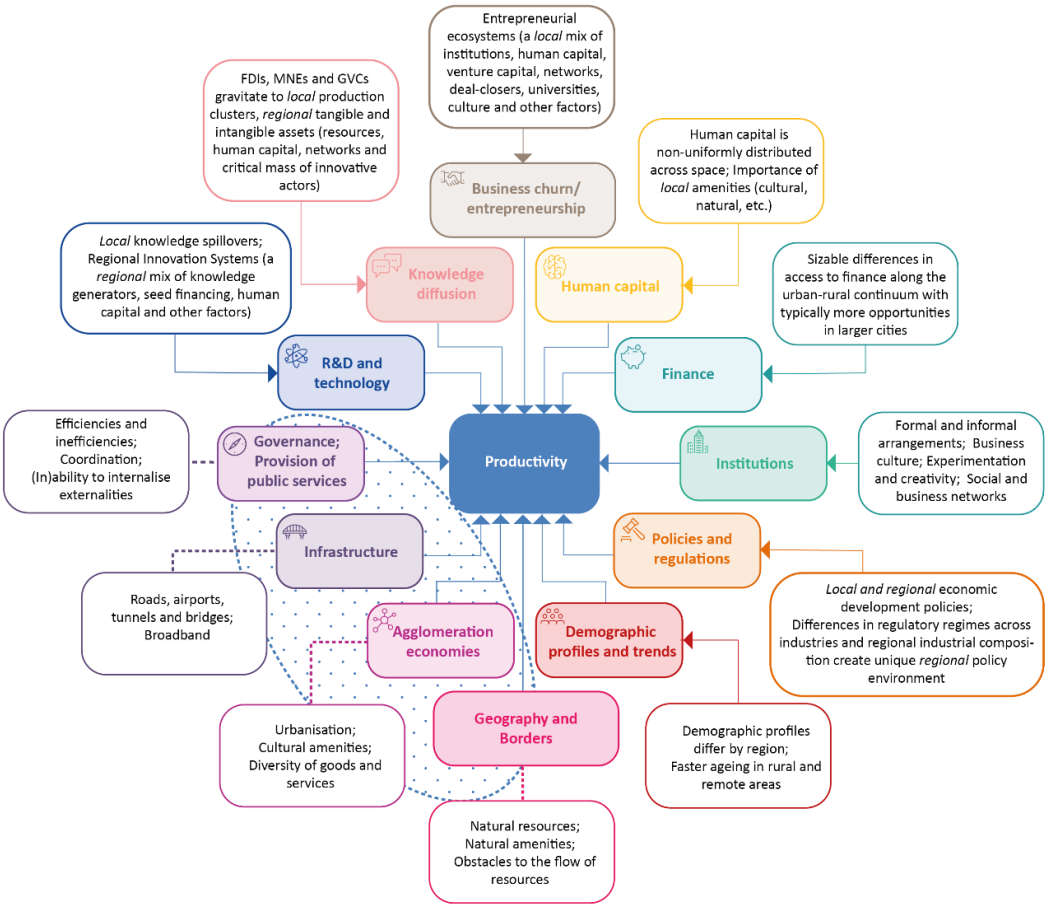
Productivity is the main determinant of living standards. Productivity growth, however, has been falling since the beginning of the century in many OECD nations accompanied by the increasing interregional divergence in productivity performance *within* countries. The mainstream economics research, which studies the drivers of productivity at the level of industries and firms, appears to be ill-equipped to offer solutions that would reverse the widening gap across regions. An explicit focus on the spatial (subnational) dimension of productivity is needed in order to better understand the recent productivity dynamics and to devise policy solutions able to boost aggregate productivity growth and to decrease interregional inequality.

Despite being largely missing from the productivity discourse within the mainstream economics literature, the spatial dimension is an integral (but often untold) story of productivity performance. This paper offers a synopsis of the current productivity research and demonstrates how regional and local characteristics and dynamics are central to productivity outcomes across industries, firms and places.

The paper distils a (relatively narrow) range of productivity determinants from the mainstream economics research and describes the mechanisms of their effects on productivity. These determinants are R&D and technology; knowledge diffusion; business churning; human capital; institutions (both formal and informal, such as culture); policies and regulations and demographic profiles and trends. This discussion (based on the theoretical and empirical studies that omit the geographical dimension) is followed by a detailed overview of how spatial realities shape each productivity determinant in focus. Finally, several clearly spatial productivity drivers (geography and borders; agglomeration economies; infrastructure – traditional and digital; governance and the efficiency of public services provision) are presented as described mostly in the regional science research.

Figure 1 offers a snapshot of the main content. It shows the spatial underlying factors for the eight “aspatial” productivity determinants. For the “spatial” productivity determinants, it lists associated characteristics and processes that have direct effect on productivity.

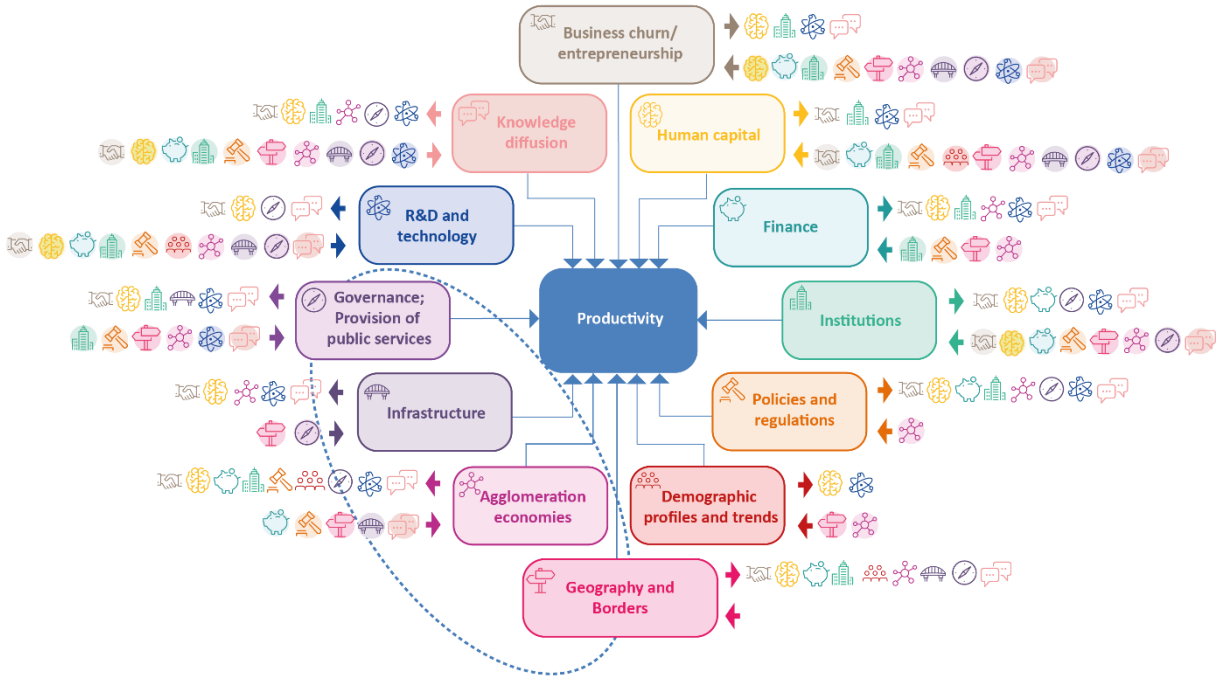
Figure 1. Productivity determinants and their spatial dimension



Note: The oval contour in the South-West corner encompasses the four determinants, which are mostly studied within the regional science literature and can be considered as "purely spatial" in nature.
Source: Own synthesis of the literature.

The productivity determinants shown in Figure 1 are often interrelated and form a complex web of mutually dependent factors that shape productivity of a region both directly and indirectly. Figure 2 presents a roadmap of the interdependencies among the discussed productivity drivers. For every productivity determinant, the outward arrow points to a range of drivers, which the given determinant influences. The inward arrow, on the other hand, originates at the group of productivity drivers, which shape the given determinant. The Figure 2 is a simplified representation of the productivity-driving dynamics, as the underlying spatial factors (which are also interdependent and affect the displayed productivity determinants and productivity performance both directly and indirectly) are omitted.

Figure 2. The interlinked nature of productivity determinants



Note: The oval contour in the South-West corner encompasses the four determinants, which are mostly studied within the regional science literature and can be considered as "purely spatial" in nature.
Source: Own synthesis of the literature.

Finally, the spatial dimension is central to the ability of various policies, both space-blind and regional, to be synchronised and to enhance each other. The policy efforts that ignore the spatial dimension are unlikely to succeed. By design, such policies cannot effectively leverage local assets and complementarities for better outcomes tailored to the local needs. The increasing productivity growth *and* the decreasing interregional inequalities can be achieved only when academic and policy discourse embrace the spatial (subnational) dimension of productivity. The policy design should strive to maximise policy complementarities stemming from the interdependent nature of productivity determinants and their embeddedness in local realities.

1 Introduction

Productivity, the efficiency of input conversion into output, is the main determinant of living standards (Easterly and Levine, 2001[1]). More productive economies have greater ability to support and enhance well-being of their citizens via higher incomes, better infrastructure, more services and other means. The drivers of productivity, and its effects on a range of social and economic outcomes, are the focus of a voluminous, long-standing and well-developed research literature. Despite the vast scholarly attention paid to productivity, its spatial dimension is generally missing from this discourse and is yet not well understood.

While productivity is ultimately driven by individual decisions of workers and companies on how to use resources in the process of value generation, regional environment conducive to and offering support infrastructure for more efficient choices is important. Many, if not all, productivity determinants studied in the international literature vary considerably at the regional and local levels. An extensive body of regional science research demonstrates subnational origins of many productivity drivers. The productivity discourse, however, often fails to link the regional nature of a number of productivity determinants to aggregate productivity (growth).

The spatial dimensions of productivity performance are becoming more salient as the global megatrends, in particular globalisation and digitalisation, affect localities differently along the urban-rural continuum. As policy makers strive to ensure spatially-inclusive growth with no places left behind, spatially-conscious productivity research is needed to inform the design of efficient policies tailored to the needs of specific places. Such policies should help the more productive regions to enhance their standing and the lagging regions to close productivity gaps.

This report offers an overview of the current productivity research placing a particular emphasis on the spatial dimension. The following observations follow from this review.

First, in the mainstream economics literature, productivity is predominantly studied within industries/sectors and/or firms. The productivity discourse identifies a range of productivity determinants and explains the mechanisms of their effects. The studies, however, ignore the spatial dimension of productivity. As a consequence, productivity debates in the mainstream economics are of limited relevance for *regional* economic growth policies and mostly cannot inform the efforts to reverse the increasing subnational productivity divergence.

Second, the spatial subnational (local, regional) dimension clearly plays a role in the ways people, firms, industries and other actors interact and function, which has both direct and indirect effects on productivity. Every productivity determinant highlighted by the mainstream economics literature has a well-defined spatial dimension. Besides, there is a set of obviously spatial productivity determinants that are mostly overlooked by the mainstream economics research but are well developed in the regional science literature.

The importance of productivity as an underlying factor of the socio-economic wellbeing and the obvious disconnect between the territorially bounded nature of many policies and the lack of detailed knowledge on the spatial dimension of productivity calls for policy-relevant research on productivity-driving mechanisms within and across various spatial contexts, as well as their interactions.

To be most useful and precise, the research efforts to better understand productivity, its determinants and the ways to boost aggregate productivity performance while reducing interregional inequalities need to rely

on better data. A census of establishment-level business microdata and the employer-employee linked data in particular appear crucial for the ability of researchers and policy makers to understand the productivity-defining processes and phenomena, as well is their interactions across space, industries, company types and other dimensions.

2 Productivity definition and measurement

Productivity is a measure of how much output an economic agent (firm, industry, region, etc.) produces out of a given amount of inputs. Since greater productivity is generally related to higher profits and wages, the determinants of productivity, as well as variations in its levels and/or growth rates, have been the focus of intensive scrutiny from both scholars and policy-makers. Recent slowdown of productivity growth in many OECD countries[1] coupled with raising subnational disparities has revived a broad interest in this phenomenon.

When it comes to empirical research, the literature adopts various ways to measure productivity depending on the specific research question, data availability and plausibility of certain assumptions about the production function. Among productivity measures, labour productivity is perhaps the most widely used followed by total factor productivity (TFP) or multifactor productivity (MFP).

The former approach usually relies on measures of GDP, output or value added per worker or hour worked (Syverson, 2017[2]; Monteiro, Gouveia and Santos, 2017[3]). Alternatively, wages[2] (Slobodnitsky, Drucker and Geva, 2018[4]; Glaeser and Resseger, 2010[5]) or per capita income (Stansel, 2005[6]) can be used as a loose approximation for labour productivity. Obviously, labour productivity depends on the intensity of other factors use and is hardly comparable across firms, industries and locations (Syverson, 2011[7]). The advantage of approximating productivity by the labour-related measures, however, is the ease of calculation and the ready applicability to all industries/sectors, including services.

A more comprehensive approach is to calculate total factor productivity or multi-factor productivity, which can be done in at least three ways. The most common one is based on the regression analysis and detailed (usually plant-level) data. A measure of output (value added) is regressed on the separate input costs. The unexplained residual is believed to capture productivity[3]. Another methodology is to calculate a ratio between output and an index number aggregating all inputs. Finally, a distance to the technological frontier can be employed as a measure of TFP performance (Capello and Lenzi, 2015[8]).

Notes

[1]See, for example, www.conference-board.org/data/economydatabase/index.cfm?id=27762. A useful overview of the slowdown and the central explanations offered in the literature (including measurement issues) is given in Andrews, Criscuolo and Gal (2016[15]).

[2] On the link between productivity and pay, see, for example, Stansbury and Summers (2017[287]).

[3] This approach is broadly based on the logic of the TFP decomposition sometimes referred to as growth accounting and attributed to the works of Solow (Solow, 1957[288]). Within this approach, growth in total output is explained by the growth in inputs, while the unexplained residual is the technological change or productivity improvement.

3 Why spatial dimension matters

Productivity and well-being of places

Productivity ultimately determines the living standards, as more productive companies are able to pay higher wages and taxes. The well-being of a region, then, is very closely linked to the performance of firms located within its borders. Given the growing subnational income inequalities across regions (Milanovic, 2016[9]), the quest is to understand the determinants of productivity (Mortensen, 2003[10]).

The main drivers of productivity have been changing over the last decades. The industrial landscape of many countries is being reshaped by globalisation, technological advance and other megatrends. As a result, the share of employment in manufacturing in the OECD area is decreasing while that of services is steadily increasing. The conventional wisdom of the 20th century that larger manufacturing companies pay higher wages (due to the economies of scale), the so-called "size-wage premium", becomes of limited relevance. Instead, productivity increasingly depends on technology adoption, innovation diffusion and human capital. The long-standing "productivity-wage premium" comes to the fore, particularly for the (ever more prevalent) services (Berlingieri, Calligaris and Criscuolo, 2018[11]).

Despite the recent increase in the tradability of services, the sector still remains mostly nontradable. This means that its performance, and productivity in particular, is largely linked to the local conditions. Services are more likely to depend on the size of the local market and on the presence of agglomeration economies.

The importance of the local conditions for productivity performance (as opposed to the national and industry-level determinants) is indirectly confirmed by the well-documented productivity dispersion across firms even within the same, narrowly defined, industries within a country (Syverson, 2011[7]; Berlingieri, Blanchenay and Criscuolo, 2017[12]). While national conditions and industrial characteristics explain some of the differences, much of them seem to depend on other factors such as subnational variation in endowments and assets.

For example, information and communication technology (ICT) adoption and innovation at a company level is often cited as a driver of divergent productivity outcomes (Sorbe et al., 2019[13]; Gal et al., 2019[14]). The adoption of ICT and other advanced technologies, in turn, is driven by the human capital of a firm (its absorptive capacity), exposure to foreign markets and embeddedness into global knowledge flows (e.g. being a part of a multi-national enterprise or MNE) among others (Andrews, Criscuolo and Gal, 2016[15]). All of these factors are not uniformly distributed in space and, as will be demonstrated in this paper, have a clear-cut spatial dimension.

The regional inequalities in well-being are even larger if they are measured in a more holistic manner (Veneri and Murtin, 2016[16]), i.e. by accounting for broader aspects of the economic and social environment (Coyle, 2018[17]). For example, the OECD *Regional Well-Being* framework (OECD, 2015[18]) integrates the traditional material conditions (income, earnings and housing) with extensive quality of life indicators (*inter alia* health, education, social connectivity, environmental quality) and future well-being resources (natural, human, economic and social capital). The UN Human Development Index (HDI) measures life expectancy, education and income per capita, while the EU *Quality of Life Indicators* include employment, environmental and social exclusion data.

Another measure that captures how gains from productivity growth are distributed within society is inclusiveness. The OECD has developed the *Inclusiveness Composite Indicator* (ICI), which accounts for various types of unemployment and work intensity, material deprivation, poverty risk and educational attainment. Based on the ICI, current evidence on the spatial variation in the inclusiveness of European regions shows substantial national and regional divergence. In particular, since 2010, between-country differences account for 57% of total variation in inclusiveness, while the remaining 43% is due to within-country variation, stemming from different characteristics of local economies (OECD, 2018[19]). Given the subnational disparities, the focus on productivity *at a regional level* is needed more than ever, as many facets of the holistic well-being and inclusiveness measures are linked to the regional (spatial) realities.

It follows that local and regional conditions are important for regional productivity, earnings and well-being and can explain – at least in part – the growing subnational disparities. This also means that the policy efforts devoid of an explicit spatial dimension are likely to be unable to successfully leverage local assets for more efficient outcomes tailored to the local needs. Focusing research and policy efforts on productivity from a subnational perspective can facilitate both aggregate productivity growth and a decrease in regional inequalities.

Subnational policies for balanced and inclusive growth

Successful policies should seek to enhance productivity, well-being and social inclusion based on a dual typology of policy design and implementation. First, a synergy between national and regional policies is necessary. Second, different types of regions (metropolitan, urban, rural) require a different policy mix.

Nationally designed monetary and fiscal policies ensure a stable macroeconomic environment that increases the potential of investment measures to promote productivity and also cushions the negative shocks on households in the lower half of the income distribution (Adalet McGowan and Andrews, 2015[20]). A range of other national policies such as market regulations (Nicoletti and Scarpetta, 2003[21]; Andrews, Criscuolo and Gal, 2016[15]) have been shown to be important for productivity. A different set of national conditions within the policy reach, e.g. union activity, minimum wage and others can be related to the link between productivity and earnings (Berlingieri, Blanchenay and Criscuolo, 2017[12]).

It is important that development policies also address the goal of a less unequal distribution of productivity benefits. One of the conditions to achieve this is a design and implementation of structural policies that are based on the local economic, social, demographic and labour market conditions. For instance, rigid employment regulations have larger detrimental effects in lagging regions with thinner labour markets and a low share of high-skilled employees (D'Costa, Garcilazo and Oliveira Martins, 2019[22]).

Likewise, a range of productivity- and inclusion-enhancing policies called for by the mainstream productivity research, such as increased connectivity between industry and universities, labour training initiatives and more opportunities for interactions that would promote technology and knowledge diffusion, seem to be better tackled at the subnational level with regional and local conditions in mind.

4 Bringing space into productivity discourse: Overview and synthesis

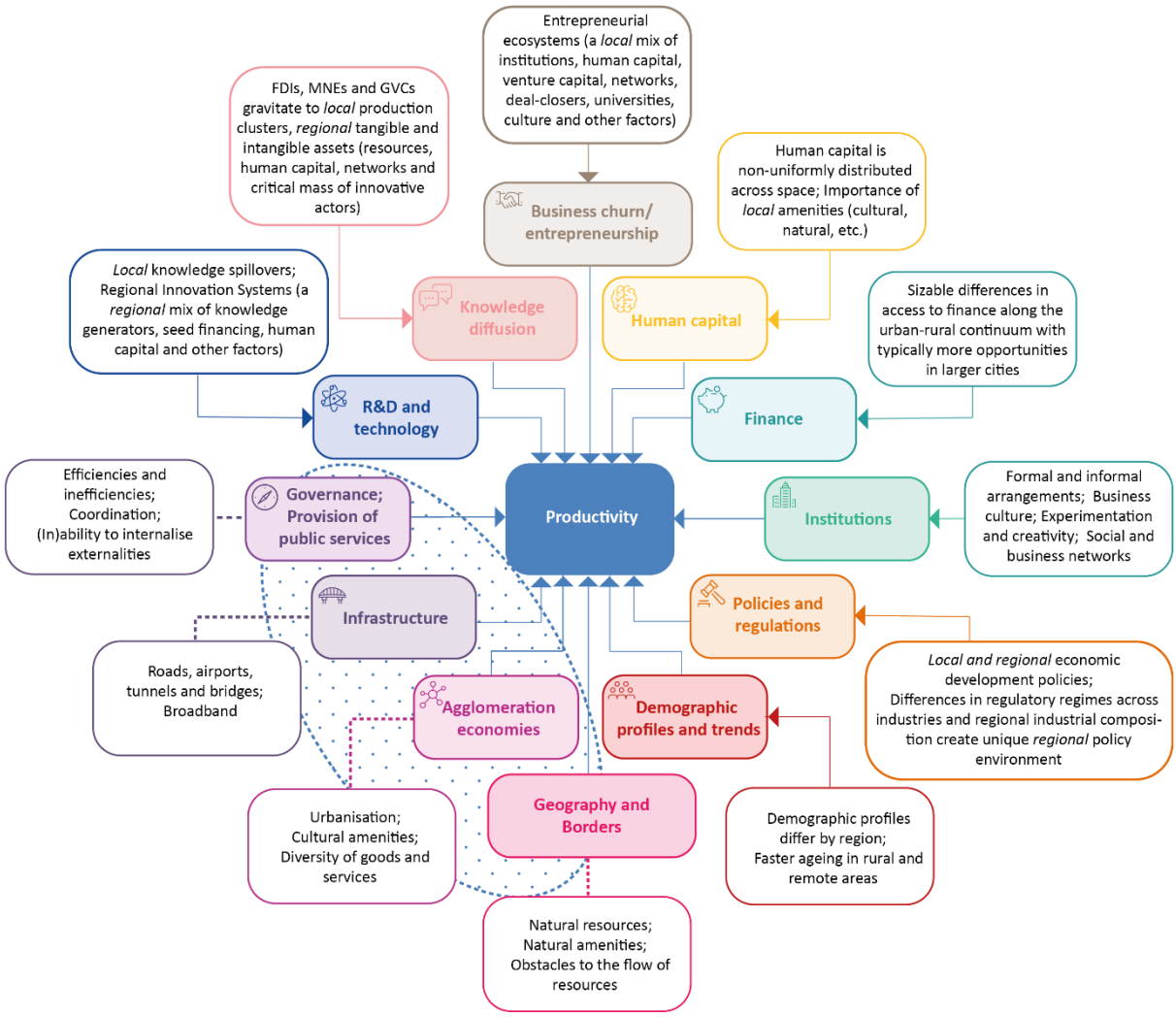
Regions, and space in general, have always been an obvious but untold part of the productivity story. A vast international literature demonstrates the importance of a range of factors, such as human capital, technological advance and innovation, competition and business churning, institutions and policies, for productivity of industries and sectors across countries. This literature usually does not consider the subnational dimension of the productivity drivers it studies. It also generally ignores a number of subnational phenomena that have been shown to shape productivity performance at various levels of aggregation.

At the same time, the regional science research tradition investigates (from a regional and local perspectives) many, if not all, productivity determinants underscored by the international productivity studies. It seeks to understand and explain a multitude of social and economic processes, explicitly modelling them as a result of regional and local dynamics. Among prominent research topics within this literature are agglomeration economies, entrepreneurship, business churn; innovation, R&D and knowledge spillovers; universities; human and social capital; networks; business dynamics and structural change among others. All of these factors, imbedded in the subnational space, are linked directly and indirectly to productivity determinants highlighted by the international productivity research.

Figure 4.1 presents a schematic overview of both international literature on productivity and the regional science studies that elucidate the ways, in which the “traditional” productivity drivers are shaped by regional factors. The determinants that are displayed immediately linked to productivity (the inner circle of shaded blocks) are derived from studies that have productivity (or in some cases other economic processes that are plausibly related to productivity) as the dependent variables. All of these determinants, except the four “spatial” ones, follow from the studies that are based on industry/sector or firm-level analyses and omit any geographical dimension. The outermost blocks contain either a succinct descriptions of the spatially-defined mechanisms that shape the “aspatial” productivity determinants displayed in the inner circle of blocks. For the spatial factors included in the oval in the south-west corner, the linked blocks display related elements, which may or may not have a causal effect on the spatial productivity drivers themselves but are nevertheless essential for the spatial variations in the productivity levels.

Figure 4.1 offers a comprehensive and coherent view on the role of spatial and aspatial factors in determining aggregate productivity performance. While succinctly displaying main relationships highlighted in the discussion below, it does not show the complex interdependencies that exist among many determinants included in the chart. Section 7 highlights some of such links.

Figure 4.1. A synthesis of the literature on productivity including spatial dimension



Note: The dotted oval in the SW corner encompasses determinants, which are mostly studied within the regional science literature and are clearly spatial in nature.
Source: Authors' elaboration based on the literature.

Another way to demonstrate the importance of space for productivity is by summarising regional variation in main productivity determinants put forth by the international productivity literature, which omits the subnational dimension. Table 4.1 shows the summary statistics for selected measures taken from the OECD Stats regional database. The measures are organised around several productivity drivers shown in Table 4.1. The values reported in the table are either standardised or are expressed as shares in order to capture heterogeneity that is not driven by the size of a region.

Table 4.1 confirms a common observation in the regional science literature that many resources (including human capital, R&D and others) are not uniformly distributed geographically. There is a significant variation at the subnational level as evidenced by large differences between the minimum and the maximum values of the variables and the overdispersion in some cases. Although not displayed, there are also notable dissimilarities of regional industrial structures measured by employment shares across sectors. It is likely to translate into varying regional competitive and regulatory regimes, as many policies and regulations are sector-specific.

Table 4.1. Regional variations in productivity determinants

Productivity determinants	Measure	Obs.	Mean	Std. Deviation	Min	Max
R&D and technology	PCT patent applications per million inhabitants (fractional count; by inventor and priority year) - level	473	69.5	106.2	0.0	749.7
	Share of R&D total expenditure (in % of GDP)	266	1.4	1.1	0.0	5.7
	Share of employment in high-technology manufacturing	149	1.1	0.8	0.1	3.9
	Share of employment in knowledge-intensive services	233	36.5	10.5	13.4	62.1
Knowledge diffusion	Share of PCT co-patent applications that are done within the country (in % of co-patent applications, total count)	376	15.3	16.8	0.3	100.0
	Share of PCT co-patent applications that are done with foreign regions (in % of co-patent applications, total count)	469	54.8	22.0	4.5	100.0
	Share of PCT co-patent applications that are done within the region (in % of co-patent applications, total count)	413	42.9	22.0	2.9	100.0
Business churn	Density of births, all firms (number of births divided by 1 000 population)	154	7.3	4.2	2.5	29.9
	Birth rate (in % of all firms - same sector, same size class)	154	10.9	3.6	5.4	25.1
	Churn rate (births plus deaths in % of all firms - same sector, same size class)	128	19.6	6.0	11.0	43.9
Human capital	Share of labour force with secondary education	507	42.1	14.7	12.0	76.5
	Share of labour force with tertiary education	507	33.3	14.3	6.0	75.2

Note: Data at the TL2 level; measures for business churn are reported for 2014 using industry, construction and services excluding insurance activities of holding companies (total economy aggregate 3 based on ISIC Rev.4 codes); all other variables are reported for year 2015.
Source: Aggregation from the OECD.Stat regional database.

To illustrate, the density of firm births per 1 000 population is usually two to three times higher in the capital regions compared to the least dynamic places in the OECD countries. In 2014, the capital regions of Prague and Bratislava enjoyed more than 20 business entries per thousand of population. At the same time, for many regions in Romania, Italy, France, UK and other countries this indicator was five or less. Another example is the number of patent applications per million inhabitants. The OECD.Stat database reports this measure for more than 450 TL2 regions. Slightly over 10% of these regions had one or no patent applications in 2015. On the other extreme, five regions (Massachusetts, USA; Vorarlberg, Austria; Stockholm, Sweden; Southern-Kanto, Japan and North Brabant, The Netherlands) filed more than 500 applications per million of residents.

In sum, if determinants of productivity vary widely across space, it is not unreasonable to expect productivity to be at least partially linked to regional characteristics. This brings the spatial dimension into the productivity debate. An explicit focus on a subnational regional dimension must be an integral part of the productivity discourse, as it can provide a unifying lens to connect regional policies to regional productivity and wellbeing as well as aggregate national productivity performance.

5 Industry and firm productivity determinants and their spatial dimension

In trying to understand and explain productivity, a vast body of literature looks at individual firms, industries or countries and does not consider the subnational (local or regional) variation in productivity performance. Such perspective is most likely driven by the specifics of the modelling approaches that start with a representative firm/technology (Coelli et al., 2005[23]) or a representative industry (Jorgenson and Stiroh, 2000[24]) and by data availability for empirical analyses (industry-level productivity compilations from statistical agencies are the easiest to obtain). The productivity research that omits the spatial dimension generally consists of the studies that try to explain firm-level productivity (or its growth), industry-level productivity (or its growth) and the vast differentials in productivity levels/growth rates across firms between and within (even narrowly defined) industries.

Regardless of the broad focus, the literature names a relatively narrow set of the factors and processes crucial for productivity performance at the national, industry and firm levels. The most prominent of them are described in a greater detail below. A summary of the (mostly international) economic studies on each productivity driver is followed by a discussion of the spatial dimension of the corresponding determinant, which demonstrates how productivity originates – to a varying degree – in the local and regional realities.

Technological advance and R&D

The mainstream economics discourse

Innovation is the basic prerequisite of a production activity – it makes production possible by generating needed technology (Doms and Bartelsman, 2000[25]). A variety of economic growth models, which identify the main productivity determinants[1], recognise this fact. The models focus on technological progress and innovation as the central sources of increased productivity at the firm-, industry- and national levels (Romer, 1990[26]; Solow, 1956[27]; Schumpeter, 1942[28]). The empirical work also confirms the defining role of the R&D and technological innovations in productivity growth (Griliches, 1979[29]; Griffith, Redding and Reenen, 2004[30]; Keller, 2000[31]; Geroski, 1995[32]).

The advent and the penetration of the information and communication technologies (ICT) have reinforced the general understanding that technological progress is a major driver of productivity growth (Jorgenson, Ho and Stiroh, 2008[33]). The ongoing rapid development of new technologies, which lead to automation and digitalisation of economic activity, suggests that the role of the R&D as a productivity determinant is likely to grow in the future.

There are several ways technology contributes to productivity growth. First, knowledge-intensive industries are on average more productive and their expansion contributes sizably to productivity. For example in the U.S., productivity growth in manufacturing is predominantly accounted for by the computer and electronic

product manufacturing industry (Houseman, Bartik and Sturgeon, 2015[34]). Devices, equipment, technologies and electronic applications produced by the knowledge-intensive industries increase efficiency and profitability of companies utilising them. The surge in productivity in the late 1990s was mostly attributed to the penetration of the ICT technologies (Jorgenson, Ho and Stiroh, 2008[33]).

Research and development naturally increase innovation but they also contribute to a greater absorptive capacity of firms and industries allowing them to benefit more from innovative activities of other economic actors (Geroski, Machin and Reenen, 2006[35]; Griffith, Redding and Reenen, 2004[30]). Existing empirical studies consistently find that the R&D investments by firms explain a large part of differences in productivity (Hall, Mairesse and Mohnen, 2010[36]), although the estimates of the R&D investment elasticity of productivity (and returns to R&D in general) vary widely (Griliches and Séneca, 2000[37]; Mairesse and Sassenou, 1991[38]). Despite the differences in the magnitude of the estimated effects, the literature is in agreement that the positive effects of the R&D and innovation are larger for high-tech firms and in high-tech or knowledge-intensive sectors (see, for example, Kancs and Siliverstovs (2016[39]); Tsai and Wang, (2004[40]); Hall and Mairesse (1995[41]) and Verspagen, (1995[42])). When productivity *growth* is concerned, the relationship is likely non-linear and a critical mass of knowledge needs to be accumulated before the positive effects of the R&D are observable in the data (Kancs and Siliverstovs, 2016[39]).

A more recent – and still relatively scant – strand of research investigates the productivity effects of automation and digitalisation, which only now are becoming prevalent. The general consensus so far is that these processes are linked to increased productivity, although the causation is not clearly established (Graetz and Michaels, 2018[43]; Koch, Manuylov and Smolka, 2019[44]; Sorbe et al., 2019[13]).

Several international studies report a positive effect of robotisation on industrial productivity. Using data on 17 developed countries, Graetz and Michaels (2018[43]) estimate that the use of robots has boosted labour productivity growth by 0.36% annually over the 1993-2007 period. The authors also report increased TFP and reduced output prises as a result of automation. Likewise, Kromann and co-authors (Kromann et al., 2016[45]) find that one standard deviation increase in the robot-intensity index is associated with more than 5% increase in total factor productivity in nine countries during 2004-2007. Similarly, a positive association between the robot adoption and productivity of manufacturing firms is documented by Dauth et al. (2018[46]) for Germany and by Kromann and Sørensen (2019[47]) for Denmark.

Although the existing empirical evidence on the productivity effects of automation is predominantly based on the analysis of how industrial robots influence manufacturing firms, automation is likely to affect sectors beyond manufacturing. The recent wave of developments in prediction algorithms, image recognition and machine translation entails potential gains in productivity for various sectors (Agrawal, Gans and Goldfarb, 2019[48]; Varian, 2018[49]).

1. When it comes to the effects of digitalization on productivity, several cross country firm-level studies report positive effects. Gal et al. (2019[14]) provide evidence that adoption of digital technologies in an industry is linked to firm-level gains in productivity. The authors document the positive effects of such technologies as cloud computing, customer relationship management and enterprise resource planning systems. Similarly, Bailin Rivares et al. (2019[50]) find that expansion of online platforms is associated with higher productivity of service firms.
2. The identification of the effect of digitalization on firm-level productivity is, however, complicated by various confounding factors such as self-selection into technology adoption. Furthermore, complementarities between digital technologies and organizational capital of firms can potentially explain why some studies find no effect (Gal et al., 2019[14]). For instance, Acemoglu et al. (2014[51]) find no association between IT-intensity and productivity in manufacturing.

The spatial dimension

The technology adoption and the R&D intensity clearly differ by industry. Enterprises comprising an industry, however, are located in space. The regional research has convincingly shown that geographical proximity is important for knowledge exchange, cross-fertilisation of ideas and the R&D intensity, which often happens in (spatially bounded) knowledge hubs. Such hubs can be industry-specific, but most often they consist of companies, which belong to a range of (related) industries and sectors[2]. The co-location (even at a micro-level) can define knowledge intensity and productivity performance (Andersson, Larsson and Wernberg, 2019[52]), although the literature suggests that various types of proximity (e.g. related and unrelated) can be conducive to enhanced innovation and productivity depending on the specific conditions (Boschma and Frenken, 2011[53]; Castaldi, Frenken and Los, 2015[54]).

Like innovation in general, the R&D and technological progress have a well-defined spatial dimension that emerges via multiple channels. They include the presence of research universities, R&D labs and a concentration of R&D-intensive industries; abundance of highly educated human capital; presence of research support infrastructure and mechanisms, e.g. seed financing, venture capital, formal and informal networks and others. These elements, when well-connected and functioning in a synergy, can form a regional innovative system (RIS) that promotes and enhances the R&D and innovation within its borders.[3]

Besides promoting business formation directly, universities and research labs considerably contribute to the knowledge-intensity of their host regions and innovativeness of the firms located therein. The literature shows that the mechanisms of firm learning from universities are manifold and complex (Cohen, Nelson and Walsh, 2002[55]; Laursen and Salter, 2004[56]). There is also some evidence that proximity to universities tends to help innovative efforts by small and medium enterprises (SMEs), those that usually would lack capacity to perform their own research (Acs, Audretsch and Feldman, 2006[57])[4] but it is crucial for firms to possess sufficient levels of absorptive capacity (Laursen and Salter, 2004[56]). Research-intensive universities can bring global knowledge flows to their host regions by absorbing cutting-edge international research and sharing its pieces relevant for businesses in proximity, which normally would not be able to benefit from global knowledge creation independently (Fritsch and Schwirten, 1999[58]).

Highly successful research universities often serve as the focal point for a regional innovation system development. The RIS approach emphasises the role of local factors and of their system-like interactions in the innovative behaviour of and knowledge production by firms (Mason and Brown, 2014[59]). While connections to the global knowledge pipelines are important for knowledge creation within the RIS, the innovative activities of firms can be perceived as a locally driven process deeply influenced by local networks and resources, including tacit and context-specific knowledge (Asheim and Isaksen, 2002[60]).

The spatial dimension appears to be important for the patterns of penetration/adoption and the productivity effects of more recent technological advances such as automation, robotisation and digitisation. Although the literature is still scant, it has already been argued that, for example, expertise in artificial intelligence (AI) tends to concentrate in space with clusters expanding around the existing IT hubs and major research departments (Goldfarb and Trefler, 2018[61]; Klinger, Mateos-Garcia and Stathoulopoulos, 2018[62]). The availability of talent appears to be essential to the location decisions of the AI research units.

The recent advances in the AI research broaden the range of tasks that can be automated, although some tasks are more prone to automation than others. As tasks and jobs embodying these tasks are unevenly distributed in space, so is the risk of automation. The estimates of the share of jobs at risk of automation across the OECD regions vary widely (OECD, 2018[19]), implying sizable regional differences in the potential gains in productivity. Besides the spatial variation in tasks that can be automated, the degree of regional exposure to automation is likely to be influenced by the existing industrial structures. For instance, Dauth et al. (2018[46]) report that the penetration of industrial robots in German labour markets is linked to the size of the manufacturing sector.

Apart from the existing industrial structure, the spatial variation in productivity gains from automation and digitalization is likely to further increase. There is growing evidence that the propensity to adopt automation and digitalisation technologies is related to firm characteristics, most importantly to firm size. For instance, in the case of automation, it has been shown that larger and more productive firms are more likely to adopt robots (Koch, Manuylov and Smolka, 2019[44]), to benefit from network externalities (Goldfarb and Trefler, 2018[61]) and to get better access to data (Cockburn, Henderson and Stern, 2018[63]). Likewise, larger firms are more likely to adopt such digital technologies as cloud computing (OECD, 2017[64]). At the same time, larger firms and more productive firms tend to concentrate in larger cities (Behrens, Duranton and Robert-Nicoud, 2014[65]), which means that the propensity of regions to rely on digital technologies and automation differs across space, and along the urban-rural continuum in particular.

Knowledge diffusion

The mainstream economics discourse

After an innovation has generated a technology needed for the production activity, the diffusion and adoption of the technology determines productivity of each establishment, which, in turn, defines aggregate productivity of an industry or a country (Doms and Bartelsman, 2000[25]). Knowledge diffusion, therefore, is a central productivity-defining mechanism together with innovation. The technology and knowledge diffusion are becoming increasingly important in a globalised world where multinational enterprises (MNEs), foreign direct investments (FDIs) and global value chains (GVCs) emerge as the leading channels of knowledge sharing across regions and nations[5].

MNEs are generally expected to be the productivity leaders as it takes a superior technology, management and other firm-specific resources to stay competitive in foreign markets (Criscuolo and Martin, 2009[66]). Multinationals usually enter foreign markets via greenfield investments (where new companies are set up to operate in a country different from the location of headquarters) and via mergers and acquisitions (M&A) with local firms. The latter channel is substantially more common and may account for 80-90% of the FDI flows (Navaretti, Venables and Barry, 2006[67]; Stiebale and Reize, 2011[68]).

As in the case of international engagement, the non-random process of firm selection for M&A and the self-selection of the headquarters into engaging in international activities complicates causal inference. Several studies seek to identify the impact of foreign ownership on productivity while properly accounting for endogeneity and other possible threats to validity of the estimates. The results tend to differ depending on the country and the industrial setting.

For example, Arnold and Javorcik (2009[69]) report strong and lasting productivity-enhancing effects of foreign acquisitions on plant performance in Indonesia, which happen via restructuring, increased investments and other channels. In a group of advanced European countries, on the other hand, the effects are modest, are detectable with a multi-year delay and only if the majority stake is acquired (Fons-Rosen et al., 2013[70]). Divergent findings come also from the UK. A study by Bloom, Sadun and Van Reenen (2012[71]) finds that companies acquired by MNEs from the U.S. tend to exhibit better productivity performance. This effect is driven by a more efficient utilisation of information technology (IT) and by superior personnel management practices. In contrast, Criscuolo and Martin (2009[66]) argue that the productivity advantage of the U.S.-owned manufacturing companies in the UK is the result of acquisitions of already highly productive companies. Almeida (2007[72]) comes to a somewhat comparable conclusion in the analysis of employer-employee matched data on Portuguese firms. The author reports negligible effects of foreign acquisitions on human capital and wages of the target companies and concludes that foreign investors choose domestic firms that are already very similar to the foreign firms.

One way for the international engagement to affect productivity is by the greater innovation of participating firms. Criscuolo, Haskel and Slaughter (2010[73]) look at the performance of the UK enterprises that are a

part of MNEs (both British-based and foreign) or are engaged in the export activities. The authors contrast these companies with the performance of purely domestic firms. The findings suggest systematic differences in the knowledge production and innovative activities of the two types of companies with the former employing more R&D staff, enjoying more inter-company learning and being more likely to patent and to introduce innovations. The differences in innovative outputs, however, are mostly explained by the variation in the amount of inputs, whilst global engagement accounts for a very small fraction of variation in the innovative performance. Guadalupe, Kuzmina and Thomas (2012[74]) examine innovative behaviour of 2,800 Spanish manufacturing firms and find that foreign ownership makes companies more likely to innovate. This leads to productivity improvements via both better technologies and a more efficient organisation of production. In contrast, Stiebale and Reize (2011[68]) estimate the effects of the cross-border M&As on innovative performance of target small and medium enterprises (SMEs) in Germany. After controlling for selection and endogeneity, the researchers find that foreign acquisitions tend to suppress innovative activities and the average R&D expenditures.

Besides affecting the performance of the target firms, FDIs and MNEs can increase productivity of domestic firms in the same or related industries via spillovers. An analysis of productivity gains among 1,300 U.S. manufacturing firms by Keller and Yeaple (2009[75]) reveals that FDIs have strong technological within- and across-industry spillovers and are able to increase productivity of domestic companies, particularly in the high-tech sector. The positive effects are also stronger for small and less productive firms.

Finally, as production becomes increasingly fragmented across national borders, the role of GVCs as a channel of knowledge diffusion becomes more salient. MNEs play an important role in proliferation and shaping of global value chains, which grow in complexity and can be based on multiple integration mechanisms, from forward and backward linkages to outsourcing (Criscuolo and Timmis, 2017[76]).

Although the literature is still scarce, it is clear that the GVC engagement can affect productivity in many ways. For the firms participating in GVCs, efficiency can be improved via integration in international trade, specialisation, offshoring, knowledge sharing and scaling up. There are also substantial inter-industry spillovers for enterprises not directly involved in GVCs. The spillovers happen via knowledge diffusion within supply chains (mostly backward linkages (Havranek and Irsova, 2011[77])), and other channels.

The FDIs, MNEs and GVCs are by definition international[6]. When making location decisions, MNEs consider a host of national factors such as regulatory and legal frameworks, labour market regulations, protection of property rights and contract enforcement among others. There is evidence, however, that the preferences of MNEs for the national aspects are highly heterogeneous and depend to a large degree on a sector and business function (Ascani, Crescenzi and Iammarino, 2016[78]).

The spatial dimension

At the subnational level, the local dynamics is important for knowledge diffusion across both regions and firms. For example, the literature documents a growing importance of local assets for the location choices of MNEs (Crescenzi, Pietrobelli and Rabellotti, 2016[79]; Iammarino and McCann, 2013[80]). This is particularly true for the high value added activities within the GVCs, which centre around regional production clusters (Criscuolo and Timmis, 2017[76]) and for the high-tech MNEs, which are attracted to the local expertise and knowledge (Crescenzi, Pietrobelli and Rabellotti, 2014[81]).

As a result, the inter-regional knowledge diffusion within the global pipelines, of which MNEs and GVCs are the central conduits, is increasingly seen via the global-local perspective. This perspective blends the patterns of knowledge diffusion and regional development as an interrelated and simultaneous process (Crescenzi and Iammarino, 2017[82]). MNEs break a complex productive process of value creation into a multitude of stages and components (ranging from functions to specific transactions). The components are placed across the globe where they can be carried out most efficiently. The location selection takes into

account the ability of GVC and MNEs to tap into local and regional intangible assets and knowledge bases relevant to each specific function or transaction.

The intangible assets specific to a region are embedded in its human capital, local networks and a critical mass of innovation actors (Kramer et al., 2011[83]) and can become central sources of competitive advantages for the MNEs (Cantwell and Iammarino, 2005[84]; Molero and Garcia, 2008[85]). Attracted by regional characteristics, MNEs can spread international expertise and best practices to local economy, although there are also concerns over knowledge sourcing by MNEs, which can undermine local knowledge bases (De Propris and Driffield, 2005[86]).

The empirical research documents the increased productivity of domestic firms in the regions of FDIs for a number of sectors but highlights that these effects are unlikely to travel past regional borders (Girma and Wakelin, 2007[87]; Higoacuten and Vasilakos, 2011[88]). At the regional level, the concentration of multinationals in the US commuting zones appears to increase value added, wages (for higher-paid workers) and employment (Setzler and Tintelnot, 2019[89]) but an appropriate level of pre-existing absorptive capacity is needed for a region to be able to benefit from the FDIs (De Propris and Driffield, 2005[86]).

For the knowledge-intensive operations of the MNEs, regions with a solid knowledge and research base are more attractive. Local knowledge hubs, often centered around local universities, may play a pivotal role in attracting the R&D-related operations of the MNEs and high value added activities within the GVCs (Broström, Mckelvey and Sandström, 2009[90]). The evidence on the link between FDIs and local innovation output of their host regions suggests that there can be both positive and negative spillovers depending on the FDI types (Ascani and Morrison, 2019[91]).

Universities often facilitate the inter-firm knowledge diffusion as well, in particular when active technology transfer offices are in place. As universities increasingly take up the role of the local economic growth engines, their TTOs are engaged in a range of activities from licencing out university-generated technologies to launching innovation parks and other incubators for business. The economic effects of such activities appear to be sizable. For the U.S., a recent report estimates that the contribution to the GDP of the non-profit inventions coming from universities and research centres ranged from 148 billion to 591 billion, in 2009 U.S. dollars, over the 1996-2015 period (Pressman et al., 2017[92]).

Overall, the diffusion of knowledge happens via multiple channels, such as labour mobility, interactions with suppliers, clients and competitors, licencing, tapping into the “local buzz”, observing actions of others as well as participation in various networks. Again, many of these channels are localised. For example, specific suppliers can concentrate in spatially bounded clusters, high-skilled labour is likely to gravitate to areas with certain level of amenities, and decisions to locate in new markets are often driven by the presence of other MNEs in the area.

Business churn and competition

The mainstream economics discourse

Innovation, in addition to increasing productivity of the innovating firms, intensifies competition, which forces incumbents to become more efficient and facilitates reallocation of resources from less efficient to more efficient businesses within the economy. In line with the argument of creative destruction, where new innovative firms replace the less innovative incumbents (Schumpeter, 1942[28]), innovation and technological evolution are often modelled as a process of adoption of new products and processes, which inevitably leads to the destruction of their old counterparts (Foster, Haltiwanger and Krizan, 2001[93]). A variety of theoretical models within this tradition shows how greater business entry and exit (churn) can be productivity-enhancing. In the model by Aghion and Howitt (1990[94]), for example, innovator firms enter

the market to derive monopolistic rents on their innovative technology until new entrants come rendering the existing technologies obsolete and pushing existing (less productive) firms out of the market. In a related manner, average productivity can increase via business churn if only new firms can possess new vintages of capital, which are more technologically advanced and productive (Campbell, 1998[95]). Another variation of this theoretical mechanism is when only start-ups embed new (more efficient) management styles or organisational structures (Nelson and Winter, 1982[96]).

Recent empirical research confirms a central role of business churn (and of business dynamism in general) in productivity growth. For example, Foster, Haltiwanger and Krizan (2001[93]) estimate that during the 1977-87, net entry accounted for 25% of productivity growth in the U.S. manufacturing. Asturias, Hur, Kehoe and Ruhl (2019[97]) come to a comparable conclusion using manufacturing data for South Korea and Chile. In a more recent study covering all private sectors except farming in the U.S., Alon, Berger, Dent and Pugsley (2018[98]) report that for 1% decline in business entry local productivity growth is reduced by 1-2%.

Business entry enhances productivity via several channels. Start-ups tend to bring new technologies and production processes to market driving up the overall efficiency of the economy (if start-ups are more efficient than incumbents). If new firms are indeed more efficient and market reallocates resources to such companies, overall efficiency will increase due to an expanding market share of more efficient firms. Besides, entry (and a threat of entry and exit) imposes competitive pressure that forces incumbents to become more innovative (Aghion et al., 2005[99]) and to improve their business processes and production practices (Nickell, 1996[100]).

The ability of an increase in entry to enhance productivity of incumbents is explored in Aghion et al. (2004[101]). The authors report faster total factor productivity growth of domestic companies in industries with greater share of foreign firm employment after the reforms, which opened the UK market during the 1980. Aghion et al. (2005[99]) estimate the effect of product market competition further demonstrating that it stimulates innovation. This relationship, however, is not uniform. A threat of technologically advanced entry increases innovation in sectors close to the technological frontier (Aghion and Howitt, 2006[102]) and suppresses innovation in the laggard sectors (Aghion et al., 2009[103]). A positive effect is observed also in the markets with neck-to-neck competition (Aghion and Howitt, 2006[102]).

A related strand of literature explores the effects of trade on productivity. The logic behind the effects is identical to the case of innovation and business entry. In order to stay competitive in international markets, firms face greater pressure to innovate and to be efficient. The same applies in domestic markets with fierce international competition from foreign exporters. Simultaneously, engagement in international trade increases the likelihood of learning, potentially boosting firm's innovative and absorptive capacities.

The empirical evidence testing the effects of trade on productivity performance of firms is mixed. Overall, firms engaged in international activities tend to be more productive, however, factoring out causality is a challenge because of the self-selection (Bernard and Jensen, 1999[104]; Tybout, 2001[105]). Criscuolo, Haskel and Slaughter (2010[73]) demonstrate that internationally engaged firms are more likely to innovate and to learn from their international counterparts. Griffith, Redding and Van Reenen (2004[30]) show that increased imports from the frontier countries have a weakly significant positive effect on productivity growth via technology transfer, not increased innovation. This detected effect is minor compared to the impacts of R&D and human capital. Likewise, Keller and Yeaple (2009[75]) find positive spillovers from import activities but the results are not robust. In models estimated by Buccirossi, Cian, Duso, Spagnolo and Vitale (2013[106]) using the data on 22 industries in 12 OECD countries, import penetration has consistently positive effect on productivity growth. On the other hand, Bernard and Jensen (1999[104]) find that exporting manufacturers in the U.S. are not different from the non-exporters in terms of productivity and wage growth, especially in the long run.

The spatial (subnational) dimension

The spatial dimension of business churn and competition is best understood from the Schumpeterian perspective of industry evolution. Within this tradition, business churn is a flip side of entrepreneurship. Start-ups disrupt the status quo by bringing new technologies and modes of production to the market and push less innovative incumbents to exit. Empirically, entrepreneurship is often approximated by start-up rates[7], which are closely linked to exit rates (Dunne, Roberts and Samuelson, 1988[107]; Geroski, 1995[32]).

Entrepreneurship is a prominent topic of research across several fields (Acs and Audretsch, 2006[108]), many of which fall under the umbrella of regional science. A great interest in entrepreneurship arguably comes from understanding that start-ups, particularly small and innovative ones, play a central role in economic performance of regions (Acs, 2006[109]; Audretsch and Keilbach, 2004[110]; Birch, 1987[111]; Malecki, 1993[112]). It comes as no surprise that a vast literature tries to explain entrepreneurial activity within a subnational perspective (Acs et al., 2009[113]; Lee, Florida and Acs, 2004[114]; Mueller, 2006[115]; Qian, Acs and Stough, 2013[116]). A set of regional determinants of entrepreneurship highlighted in the literature include regional entrepreneurial ecosystems (EEs), universities and research organisations, human capital, a culture of openness and inclusion, creativity, social networks and access to finance among others.

Of these determinants, the EE is the youngest and, to a degree, an all-encompassing concept. Mason and Brown (2014[59]) underscore the importance of the place-specific assets for the formation of an entrepreneurial ecosystem, which is defined as "a *set of interconnected entrepreneurial actors (both potential and existing), entrepreneurial organisations (e.g. firms, venture capitalists, business angels, banks), institutions (universities, public sector agencies, financial bodies) and entrepreneurial processes (e.g. the business birth rate, numbers of high growth firms, levels of 'blockbuster entrepreneurship', number of serial entrepreneurs, degree of sell-out mentality within firms and levels of entrepreneurial ambition) which formally and informally coalesce to connect, mediate and govern the performance within the local entrepreneurial environment*" (p.5).

Although the literature is ambiguous regarding a clear delineation of the causes and consequences within entrepreneurial ecosystems due to the complex nature of interdependencies, EEs are believed to be the hotbeds of productive, high-quality or high-growth entrepreneurship (Stam, 2015[117]; Acs et al., 2017[118]; Alvedalen and Boschma, 2017[119]; Mason and Brown, 2014[59]) and are linked to greater productivity and more innovative outputs within their boundaries (Acs et al., 2017[118]).

The distinctive feature of the EE approach is its focus on the links among various types of actors (such as individuals, organisations and institutions) constituting an ecosystem instead of an isolated focus on actors themselves (Alvedalen and Boschma, 2017[119]). Because of the spatial nature of many interactions at the core of an EE, as well as the predominantly geographical organisation of an entrepreneurship support system, entrepreneurial ecosystems are geographically bounded. Despite being clearly a spatial phenomenon, EEs are not limited to specific geographical scales – they can be found in places of various sizes from a neighbourhood to a city to a region (Mason and Brown, 2014[59]; Qian, Acs and Stough, 2013[116]). Besides, entrepreneurial ecosystems can be industry-specific or include many industries (Mason and Brown, 2014[59]).

In a sense, entrepreneurial ecosystems are a precondition for the success of (much older in terms of academic and policy interest) concepts such as industrial clusters, innovation systems and knowledge economy (Isenberg, 2011[120]). EEs tend to possess unique dynamism (Mack and Mayer, 2016[121]) that leads to synergies stemming from and reinforcing diversity, (related) diversification, resilience and adaptation (Alvedalen and Boschma, 2017[119]). As a result, entrepreneurial ecosystems are able to nurture scaling-up and high-growth firms, which are central to productivity growth, increased innovation and internationalisation of their host (regional) economies (OECD, 2013[122]).

Another prominent business dynamics determinant is a presence of universities or research centres, which are often linked to increased local firm formation, particularly in knowledge-intensive and high-tech industries (Baptista and Mendonça, 2010[123]; Kirchhoff et al., 2007[124]). Many universities task their technology transfer offices (TTOs) with promoting business formation based on the in-house research. Alternatively, graduates, and sometimes employees, may choose to start a business based on an idea they were exposed to during their studies or work. In this sense, university-industry relationships can help overcome the "knowledge filter" by transforming research ideas into new businesses entry (Mueller, 2006[125]). The literature, however, points to the crucial importance of the local support infrastructure for the rates of university spin-offs and business formation in general. Usually a presence of an university is an important but not sufficient condition for sprouting a vibrant entrepreneurial culture (Di Gregorio and Shane, 2003[126]; Feldman, 2001[127]), much in line with the entrepreneurial ecosystems argument.

Human capital available regionally is an intensively studied explanation of regional economic dynamism and is an integral part of the EE perspective (Spigel, 2017[128]). Human capital is crucial for the success of entrepreneurial ecosystems and scaling-up, as well as for the regional entrepreneurship in general. The importance of educational attainment (perhaps the most common measure of human capital) for local and regional entrepreneurship is determined by several factors. Besides providing skilled labour force to be employed by new ventures, higher levels of education in an area increase regional absorptive capacity. This can facilitate knowledge-spillover entrepreneurship, i.e. a process of utilising entrepreneurial opportunities generated by locally produced knowledge, which usually requires the ability to understand and apply this knowledge (Qian, Acs and Stough, 2013[116]).

The notion of human capital here is not limited to the skills of graduates (or educational attainment of the population). It also includes the accumulated managerial experience (including managing failed ventures) and developed networks that allow leveraging local resources and connecting to global pipelines efficiently. Vibrant entrepreneurial ecosystems are characterised by the process of entrepreneurial recycling (Mason and Brown, 2014[59]; Mason and Harrison, 2006[129]) where successful (cashed-out) entrepreneurs reinvest their resources in local entrepreneurial activity. For example, Amaral, Baptista and Lima (2011[130]) show (using data for Portugal) that for younger entrepreneurs (under 30 years old) having a top managerial experience in a previously closed enterprise decreases time to the next entrepreneurial entry.

Empirical literature also demonstrates that a culture of openness and inclusion often plays an important role in stimulating both entrepreneurship and entrepreneurial recycling. For example, Qian at al. (2013[116]) find that tolerance (measured by the share of households with reported homosexual unmarried partner and by the share of bohemian population) is positively associated (the study design does not allow to identify causal effects) with the rate of business start-ups in the U.S. metropolitan areas. The estimated coefficients are larger for the high-technology start-up activity in particular. In a related manner, Sobel, Dutta and Roy (2010[131]) show that entrepreneurship is positively related to ethnolinguistic fragmentation in the U.S. states. For German regions, Audretsch, Dohse and Niebuhr (2010[132]) report a positive effect of cultural diversity on technology-oriented start-ups.

A local culture of accepting business failure is another example of openness that stimulates business churn within a regional perspective. In a study of a start-up community in Boulder, Colorado (USA), Feld (2012[133]) argues that its success is partially based on a lack of stigma related to changing employers or to business failure. Failed entrepreneurs are absorbed by the business community as advisors or become serial entrepreneurs. Likewise, Isenberg (2011[120]) argues that quick experimentation in business ideas (with quick start-ups and exits if a project does not generate expected value) is vital to the vibrancy of entrepreneurial community – the cultures that encourage quick exits enjoy higher rates of entrepreneurial activity.

Experimentation is intrinsically related to creativity, another important aspect of local culture that may stimulate entrepreneurship and business churn. Florida (2003[134]) argues that there are three types of creativity – technological (innovation), economic (entrepreneurship) and artistic or cultural creativity.

According to this scholar, these three types reinforce each other; for a region to succeed in entrepreneurship, conditions must be created for thriving technological and cultural creativity. While highly influential, the Florida's approach was widely criticised for the fuzziness of the main concepts and an overly casual treatment of the cause-and-effect relationships (Markusen, 2006[135]; Peck, 2005[136]; Asheim and Hansen, 2009[137]). The empirical evidence testing Florida's propositions is mixed. The existing research also suggests that the direct and large effects of creativity and of creative class on regional economic performance are unlikely (Krätke, 2010[138]; Boschma and Fritsch, 2009[139]; Rausch and Negrey, 2006[140]) but creativity might play an auxiliary role enhancing the contribution (or facilitating geographical concentration) of other factors (Audretsch and Belitski, 2013[141]). For example, cultural industries and occupations can facilitate innovation and greater customer satisfaction via supplying content and designs to the technology sectors and the economy of experience (Cooke and de Propris, 2011[142]).

Finally, a sociological and management traditions study extensively social networks. Although this approach is not directly related to a region and focuses instead on entrepreneurial opportunities and available resources as a function of embeddedness in various types of social connections (Stuart and Sorenson, 2005[143]), the latter tend to have a clear spatial dimension. As a result, networks partially determine local business opportunities (business ideas that can be utilised by start-ups) and resources to establish a firm based on these ideas. In terms of business start-ups, the role of networks often comes via facilitating access to financing (Jenssen and Koenig, 2002[144]; Stuart, Hoang and Hybels, 1999[145]).

Unlike business entry, which often is a regional phenomenon regardless of industry or sector, the regional dimensions of competition are clearly industry-dependent. Here local conditions (including the local number and market strength of competitors) would be relevant mostly for non-tradable industries. The competitiveness and the overall quality of the non-tradable industries in a region, however, are important for the performance of the local companies in the tradable sectors, as the former supply goods and services, which are the inputs into the productive activities of the latter. A range of other local determinants play an important role in the competitiveness of a tradable sector within a region. In words of Michael Porter (1998, p. 78[146]) "the enduring competitive advantages in a global economy lie increasingly in local things – knowledge, relationships, motivations".

Human capital

The mainstream economics discourse

Examining the effects of technology, knowledge and innovation on productivity performance of firms, industries and nations tells only a part of the story. Human capital, an important ingredient of any production function, is equally important. The role of human capital (in a broad sense) in determining productivity differentials comes via at least three channels. First, managerial ability[8] is strongly correlated with performance, as managers are the ones deciding how resources are being combined in a productive process (Syverson, 2011). Next, in line with the traditional growth theories, labour can be treated as a regular input (Mankiw, Romer & Weil, 1992). Greater levels of human capital are likely to contribute to (labour) productivity directly, as more educated and more skilled labour force should be able to produce more per hour. Finally, in the spirit of the endogenous growth theories, the quality of human capital is crucial for technological progress, as it determines the efficiency of utilisation of other resources, most importantly, of advanced technologies.

The evidence on the productivity-enhancing impacts of managerial practices and talent is described in Syverson (2011[7]) who notes that the differences in business performance were attributed to the managerial ability more than a hundred years ago (Walker, 1887[147]). Besides being able to control and streamline the day-to-day operations, managers are often responsible for the choice of technology and the use of various resources in the production process of a firm. The interdependence in the ways inputs

determine productivity (Doms and Bartelsman, 2000[25]) makes managerial decisions, such as allocation of resources within a company, its structure and others, even more consequential for productivity performance. Bloom, Sadun and Van Reenen (2016[148]) provide supporting evidence. Using data on 34 countries, the authors find that differences in management practices can explain around 30% of variation in productivity between countries as well as within countries across firms.

Within the human capital – growth nexus, Benhabib and Spiegel (1994[149]) model the influence of human capital on growth via its ability to facilitate national innovation and diffusion of technologies, as suggested by the endogenous growth theories. The human capital is found to stimulate growth. Additional evidence suggests that higher levels of human capital have greater effect on growth via innovation closer to the technological frontier (Vandenbussche, Aghion and Meghir, 2006[150]).

More recent studies investigate the relationship between human capital and innovation at the firm- and industry levels. In the analysis of German SMEs, Stiebale and Reize (2011[68]) find that companies with higher levels of human capital measured by a share of employees with a university degree are more likely to innovate and to engage in the R&D. Griffith, Redding and Van Reenen (2004[30]) report that human capital is positively related to the rates of innovation and technology transfer in a panel of industries in the OECD countries.

The spatial dimension

The spatial link between the quality of human capital and productivity growth mostly comes from a great heterogeneity in the quality of human capital across (subnational) space. The uneven spatial distribution of the human capital calls for empirical analyses of its effects on productivity at a regional level.

For instance, in a study of the European regions, Marrocu, Paci and Usai (2013[151]) find a strong positive effect of human capital on productivity growth, which is larger than such effect of technological capital. In a related paper, Dettori, Marrocu and Paci (2011[152]) demonstrate that the positive impact of human capital on total factor productivity growth in the European regions is the largest compared to the effects of social and technological capital.

There is a long-standing unresolved debate whether jobs follow people or people follow jobs. The answer is likely to depend on a specific technology employed by the industry, the supply and demand conditions in the labour market and other factors. For the high value added activities and the R&D in particular, which are at the heart of productivity growth, it appears that the highly skilled workers are more likely to be able to choose where they want to live and work (Brown and Scott, 2012[153]; Graves and Linneman, 1979[154]; Rappaport, 2009[155]).

By and large, highly educated population tends to increasingly concentrate in urban areas (Shapiro, 2006[156]). This is the result of the local educational efforts (Moretti, 2004[157]) and of the in-migration of graduates (Brown and Scott, 2012[153]). Empirical literature offers plentiful and conflicting accounts as to what are the primary drivers of highly educated workers' migration choices – jobs or amenities (Brown and Scott, 2012[153]; Partridge and Rickman, 2003[158]; Scott, 2010[159]; Winters, 2011[160]). The drivers can be difficult to disentangle due to the frequent co-location of the high-quality jobs and various types of amenities. Regardless of the final jury in this debate, one conclusion is uncontested – local conditions (employment and/or the quality of life) determine to a large extent the human capital composition of a region (Buenstorf, Geissler and Krabel, 2016[161]; Falck, Fritsch and Heblich, 2011[162]).

Demography

The mainstream economics discourse

Closely related to the discussions on the link between human capital and productivity growth is the debate on the role of demography, demographic trends and of the age composition in particular. At the micro-level, as workers age, their productivity can decline mostly due to the weakening of the physical abilities and absenteeism related to the deteriorating health. The negative effects, however, can be counteracted by accumulated experience or never felt in occupations where mental ability (as opposed to the physical one) is of primary consequence (Garibaldi, Oliveira Martins and van Ours, 2011[163]).

The relevance of the age composition in the productivity discourse in the developed countries has grown over the last few decades due to the ageing of the baby boomers and the resultant shifts in the demographics of labour. The empirical consensus, at least up until very recently, was that age structure matters (Feyrer, 2007[164]) – ageing has a persistent, although small, negative effect on productivity growth (Sharpe, 2011[165]; Aiyar, Ebeke and Shao, 2016[166]).

Feyrer (2007[164]) uses international data to explore the effects of the workforce age structure on productivity. The author finds that a larger share of young population (under 40) has a suppressing effect on productivity, while the opposite is true for the population in the 40s. The results for the older cohorts (in their 50s and 60s) tend to be negative but are mostly insignificant, offering only suggestive evidence.

Another age-related productivity determinant identified in the international literature is the dependency rate, i.e. the ratio of the non-working population (usually of young age) to the working population. It is usually found to have dampening effect on growth in the OECD countries and in the EU (Lindh and Malmberg, 1999[167]; 2009[168]). Kogel (2005[169]) comes to a comparable conclusion using international data on 70 countries. More specifically, the author demonstrates that the young-age dependency ratio is linked not only to lower capital accumulation but also to a reduced TFP growth.

In light of the recent technological advances, however, the conclusions of the empirical literature on the link between ageing and productivity may not hold any more in the developed countries. As long as the age composition of the population determines the rate of labour force growth, countries that experience a lack of prime-aged workforce would be hard pressed to adopt new labour-efficient technologies (Beaudry, Collard and Green, 2005[170]).

In line with this argument, Acemoglu and Restrepo (2017[171]) demonstrate that in the last two to three decades, there was no negative relationship between ageing of the population and GDP per capita growth in a large group of countries and in the OECD area in particular. The study shows that nations undergoing more rapid demographic transitions are more likely to adopt automation technologies. If sufficient amount of capital is present, the fast and wide-spread introduction of the labour-replacing technologies allows to counteract and even reverse the negative effects of the lack of the young and middle-aged workers.

The spatial dimension

The demographic and age profiles of regions differ substantially within countries. There are substantial differences in the age composition of the rural and urban areas in the EU, for example (Van Der Gaag and de Beer, 2015[172]). If age structure of the labour force is related to productivity performance, the uneven age distribution should be linked to subnational productivity differences. The literature at the regional level, however, tends to be at least a decade old and does not directly consider the mitigating role of the age structure in the rates of technology adoption within countries.

Another limitation is that the existing studies usually focus on regions within one country and often arrive at divergent results. For example, Tang and MacLeod (2006[173]) use the 1981-2001 data for Canada to test if older workers are less productive on average. Having established that this is the case, the authors

conclude that the workforce ageing is expected to have a relatively small negative effect on productivity growth in the Canadian regions. In contrast, Skans (2008[174]) concludes that the share of the 50-60 year old workers is linked to higher productivity of Swedish regions. In Germany, Brunow and Hirte (2009[175]) discover a U-shaped relationship between the age of the available human capital (defined as the share of labour force in the high-skilled jobs) and productivity performance of NUTS3 regions with the 30-39 year olds being the least productive.

A recent study by Daniele, Honiden and Lembcke (2019[176]) is a welcome contribution to the discourse, as it brings in the international regional perspective. The study does not assess, however, the effect of aging on productivity. Instead, it estimates whether the current productivity growth across the OECD regions is sufficiently large to offset the productivity-suppressing effects of ageing. The study concludes that the productivity growth in many regions is lower than what is required. This implies that in reality, adoption of robots and other labour saving techniques is likely to lag behind the shifting demographic structure.

Finance

The mainstream economics discourse

In the most general terms, finance and financial systems are linked to economic growth via five mechanisms. Financial systems "*(1) produce information ex ante about possible investments and allocate capital, (2) monitor investments and exert corporate governance after providing finance, (3) facilitate the trading, diversification, and management of risk, (4) mobilize and pool savings and (5) ease the exchange of goods and services"* (Levine, 2005, p. 869[177]). Besides the direct effects, financial systems influence productivity performance via multiple indirect mechanisms, which are related to business dynamics (entry and exit), innovativeness of existing firms, human and physical capital accumulation among others (Heil, 2017[178]).

In the properly functioning financial systems, promising start-ups can find the financial resources needed to fund their activities, while non-productive firms go out of business because they are unable to secure financial support to stay afloat. Similarly, efficient financial systems allow companies to achieve their maximum productivity performance by providing needed resources for investment in the R&D, capital and labour.

A recent detailed review of the literature on the relationship between finance and productivity (Heil, 2017[178]) finds that policies ensuring the efficient operation of a financial system and facilitating the efficient allocation of resources in a country are a central precondition for the presence of a positive link between finance and productivity. Conversely, financial frictions, while less pronounced in the developed countries, may lead to a sub-par productivity performance.

For example, firm insolvency policies may help non-productive firms to survive, resulting in zombie-firms and slowing productivity growth. The literature also shows that inefficient policies within the banking sector can be particularly harmful to productivity growth, as they lead to resource misallocation (Duval, Hong and & Timmer, 2017[179]; Storz et al., 2017[180]; Schivardi, Sette and Tabellini, 2017[181]).

In terms of the sources of financing, there is some evidence that equity finance may be more productivity-enhancing compared to debt finance, particularly for growing young and small firms. In addition, the availability of venture capital to fund promising start-ups is positively linked to productivity, as are mergers and acquisitions. The efficiency of the latter heavily depends on the quality of information, which can also be the domain of policy regulations.

The spatial dimension

Companies, particularly the new ones, often need external financing to realise their growth potential. A lack of financing is believed to be a major impediment to growth (Fritsch and Storey, 2014[182]). While many forms of financing are available in the developed countries, access to finance can be place-specific (Ughetto, Cowling and Lee, 2019[183]). For example, investment opportunities tend to disproportionally cluster in large cities (Lee and Luca, 2018[184]) potentially suppressing productivity performance of companies located in the less central regions. At a regional level, entry of new bank branches was shown to improve access to finance for Polish companies (Hasan et al., 2019[185]).

The empirical literature, nevertheless, does not seem to agree on the ability of a shorter distance to the sources of financing to alleviate credit constraints. While some studies report the beneficial effects of proximity (Bellucci, Borisov and Zazzaro, 2013[186]), others find no effects (Carling and Lundberg, 2005[187]). Whilst the conclusive evidence on the direct effects of proximity to financing on regional productivity is lacking, the spatially-dependent access to finance can shape several economic indicators relevant for productivity performance.

Perhaps most importantly, sufficient financial resources, often attracted from outside of a firm, allow companies to begin operations and/or to scale up or engage in the R&D and other innovative activities. For instance, in an empirical analysis of Italian innovative start-ups, Grilli (2018[188]) finds that they are less likely to rely on business angel financing in regions with the weak financial systems. Evidence from the UK suggests that SMEs (particularly innovative and export-oriented one) in the peripheral regions rely more on credit card financing compared to companies in more central locations (Brown, Liñares-Zegarra and Wilson, 2019[189]). In Poland, the post-crisis restructuring of local banks was linked to an increased business entry (Hasan et al., 2019[185]).

Institutions, policies and regulations

The mainstream economics discourse

Regulations, and institutions more generally, can have a significant and lasting impact on productivity of firms and industries. A large body of both theoretical and empirical research tries to assess and quantify the degree to which productivity is driven by these factors. In addition to their ability to affect business behaviour directly, the productivity effects of institutions, policies and regulations also come indirectly by influencing other productivity determinants described above.

In the international comparisons of productivity performance, the literature underscores a central role played by institutions, which set the “playing field” and form an incentive structure (North, 1991[190]). A strong link between *national* policies and institutions on the one hand and growth on the other, including the TFP growth, is well-established (Easterly and Levine, 2001[1]). A causal relationship, however, is more difficult to establish. In a study of 127 countries, Hall and Jones (1999[191]) argue that a large fraction of variation in the output per worker comes from dissimilar institutions, which the authors call social infrastructure. A protection of property rights is particularly important for the improved performance of the economic agents and the increased productivity (North, 1991[190]).

Research at the national level also often disagrees on the types of policies that have a stronger effect on productivity. Depending on a study, policies in focus can be those related to international trade, fiscal, financial or macroeconomic affairs. For example, Edwards (1998[192]) tries to track the effects of trade openness on productivity growth and finds that TFP increases are greater in the open economies. A more recent study by Afonso and Jalles (2013[193]) suggests that the TFP also grows faster in countries with greater debt ratio. McMillan and Rodrik (2011[194]) show that in the developing countries, the undervalued currencies and the ease of resource flows contributes to the productivity-enhancing structural change.

Moving to the developed countries and to the industry-level evidence, policies and regulations affect the incentives, the ease of resource flows and other structural conditions important for economic efficiency. In this area, literature explores the effects of regulatory reforms, labour regulations, privatisation and liberalisation of markets.

Nicoletti and Scarpetta (2003[21]) assess the effects of privatisation and liberalisation across the OECD. The analysis of data for the manufacturing and service industries in 18 OECD countries reveals that policies promoting corporate governance and competition are linked to faster productivity growth. A positive effect of liberalisation on productivity in manufacturing is stronger in countries that are farther behind the productivity leader. The authors conclude that product market regulations and policies limiting business entry are detrimental to productivity growth.

Given a strong link between competition and business efficiency, policies shaping competitive environment should be related to productivity of firms, industries and countries. Buccirossi et al. (2013[106]) explore the effects of the competition policy in the OECD countries on the industry-level TFP growth. The authors rely on the instrumental variable estimation and find that a well-designed and well-implemented competition policy has a strong positive effect, which is mostly driven by the components related to institutions and antitrust regulations. The impact of policies related to competition are often industry- or market-specific. Their effects, however, tend to proliferate to other industries and sectors via the input-output linkages. To illustrate, Bourles, Cette, Lopez, Mairesse and Nicoletti (2013[195]) study how product market regulations affect multifactor productivity growth in downstream industries using data for 20 industries in 15 OECD countries. They report a negative effect of anti-competitive regulations upstream, which is particularly large closer to technological frontier.

At the same time, if competition is distorted as a result of inadequate policies or for other reasons, the non-productive zombie firms may be more likely to survive. The rise in capital and labour misallocation can be one reason for their existence (Gouveia and Osterhold, 2018[196]), which slows down the aggregate productivity growth (Cette, Fernald and Mojon, 2016[197]; Gopinath et al., 2017[198]; Andrews and Petroulakis, 2017[199]). In addition to slowing down the aggregate productivity growth, zombie firms can trap resources that otherwise would go to “healthy firms” and further distort competition (Caballero, Hoshi and Kashyap, 2008[200]; Schivardi, Sette and Tabellini, 2017[181]). From a policy perspective, lowering exit and restructuring barriers promotes the least productive companies to leave the market, while their more productive cousins may be able to restructure and increase productivity.

Finally, labour policies can affect productivity in multiple ways. A deregulation of labour market should increase the flexibility and the speed of adjustments in the economy potentially increasing its efficiency. On the other hand, deregulation (and a lack of employment protection) decreases incentives to invest in human capital (Belot, Boone and Van Ours, 2007[201]) and may lead (at least in some industries) to a greater share of temporary entry-level positions with a lower overall productivity and output (Blanchard and Landier, 2002[202]). A recent study by Damiani, Pompei and Ricci (2016[203]) documents a suppressing impact of deregulation of temporary employment on total factor productivity in 10 industries across 14 OECD countries. The effect is found to be stronger in the industries that are more likely to hire temporary workers. In line with the previous literature, the authors find that deregulation is linked to lower training and job-specific skill acquisition.

The spatial dimension

Perhaps surprisingly, there is a regional aspect to the national institutions as well as industry-wide policies and regulations. As noted by Garcilazo, Oliveira Martins and Tompson (Garcilazo, Oliveira Martins and Tompson, 2015, p. 17[204]), “spatially-blind policies may not be spatially neutral in impact”. In reality, the spatial dimension of institutions, policies and regulations is reinforced by the regional characteristics. Distance of regions to the productivity frontier, for instance, is likely to influence how responsive regions are to structural policies. Using a panel covering 265 regions from 24 OECD countries. D’Costa, Garcilazo

and Oliveira Martins (2019[22]) show that lagging regions benefit most from relaxing product and labour market rigidities, while productivity growth in regions closer to the frontier is more responsive to lowering barriers to entrepreneurship or higher government debt.

A set of other regional characteristics can determine the regionally differentiated effects of policies. To illustrate, remote regions that do not enjoy the benefits of highly concentrated and diverse economic activities, are likely to be affected more by the policies that impede entrepreneurship (Stephens and Partridge, 2011[205]; Stephens, Partridge and Faggian, 2013[206]). Likewise, labour policies would have unequal effects in more agglomerated urban regions compared to sparsely populated rural areas (Garcilazo, Oliveira Martins and Tompson, 2015[204]).

Another reason why the nation-wide industrial policies can have differential regional effects is the industrial composition of regions. As some industries tend to be more sensitive to certain policies, the industry mix of a region can determine to what extent a policy is transmitted in space (Carlino and DeFina, 1998[207]; Owyang, Rapach and Wall, 2009[208]). Furthermore, the spatial dimension in the effect of national policies is reinforced by the regional differences in the mix of large and small firms and in the strength of agglomeration effects (Owyang, Rapach and Wall, 2009[208]; Fratantoni and Schuh, 2003[209]).

At the same time, the differential impact of policies on regions can appear as a result of the difference in how nation-wide policies are implemented by regions. Implementation of policies depends on the quality of government - the extent of corruption, impartiality of public service and the rule of law - and quality of local government varies substantially within countries (Charron, Dijkstra and Lapuente, 2014[210]). For instance, Charron, Lapuente and Nistotskaya (2012[211]) study the effect of regional variation in quality of government using data on 172 regions of 18 European countries, and find that the EU regions with lower quality of government were less likely to use the Cohesion Policy funds efficiently and had lower rates of entrepreneurship.

Most importantly, there are also subnational institutions, policies and regulations, which have direct and indirect effects on economic growth of regions and places. These local development policies, not accounted for in the aggregate productivity research, can have profound effects on regional productivity. The efficient policy design in this area, however, is often hampered by a lack of systematic knowledge about what works and what does not in promoting subnational productivity and under which circumstances. This calls for rigorous policy-oriented productivity research at a regional level.

Notes

[1] These models, however, often focus on *aggregate* productivity (i.e. the total amount of output) growth and in some cases may not be directly applicable to explain *average* (amount of output per a unit of input) productivity growth, as, for example, is the case of savings rate in the AK models. The rate of savings and capital accumulation, another common explanation of growth, are related to average productivity indirectly e.g. via development and introduction of more efficient technologies and technological processes.

[2] A more comprehensive view suggests that several types of proximity are crucial for learning and information exchange: cognitive, organizational, social, institutional and geographical (Boschma, 2005[293]). While acknowledging that these types are likely to work in tandem and could be difficult to clearly disentangle in terms of effects on innovation, we predominantly focus on the geographical proximity, since it is most relevant to our discussion.

[3] Since networks and human capital are discussed in other subsections, this subsection focuses on the role of universities (and other research-intensive entities) and on regional innovation systems.

[4] For opposing evidence suggesting that the effects are larger for big firms and start-ups, see Cohen, Nelson and Walsh (2002[55]).

[5] Knowledge diffusion via engagement in international trade is also briefly discussed in Section 5.3.

[6] FDIs tend to connect neighbouring countries, making them predominantly a cross-border phenomenon, rather than a truly global one (Crescenzi and Iammarino, 2017[82]).

[7] Other common approximations are a share of firms under certain age (usually 3 or 5 years), share of self-employed and (less common) a share of firms below certain size.

[8] We take the liberty of counting managerial or entrepreneurial ability within the broad category of human capital for the sake of easier exposition. It, of course, can (and for many purposes should) be treated separately. This would change the structure of the paper but the discussion will remain the same.

6 Clearly spatial productivity determinants

A large body of regional science research examines in detail a range of factors directly related to space, which are (naturally) not a part of the mainstream productivity discourse at the national and industry level. At least four of such factors deserve special attention. Below the effects of geography and borders, agglomerations, infrastructure and urban governance on the subnational productivity performance are discussed.

Geography and borders

Geography can define economic performance via several mechanisms. The features of terrain and (the availability of) waterways have naturally shaped economic opportunities since time immemorial. Historically, the productive structures of regions tended to capitalise on the natural resources available locally[1]. Now, the legacy of the industrial composition often continues to impact human behaviour and socio-economic outcomes (Chinitz, 1961[212]; Michaels, 2011[213]).

Political fragmentation can also be linked to the "protective" features of the landscape where national borders are more likely to follow mountains and rivers. As a result, areas with more rigged and otherwise "disrupted" space usually host more nation states. State fragmentation tends to be associated with better economic outcomes (at least in Europe), although the benefits accrue mainly to the central parts of the countries with border regions generally being underdeveloped (Kitamura and Lagerlöf, 2019[214]).

An introduction of a border disrupts socio-economic space and processes (Capello, Caragliu and Fratesi, 2018[215]). By increasing transportation costs for the trading partners, new borders can shift economic activity away from the border regions and create new economic hubs. Following the division of Germany after the Second World War, for instance, border regions have experienced a disproportionate loss in economic activity relative to the regions further away (Redding and Sturm, 2008[216]; Ahlfeldt et al., 2015[217]). If the creation of new hubs involves large sunk costs and is reinforced by network externalities, the resulting reorganization of economic space can be long-lasting even after the borders are removed (Redding, Sturm and Wolf, 2011[218]; Burda et al., 2006[219]). This was the case when Germany's main air hub was relocated from Berlin to Frankfurt in the 1940s. After the reunification, Frankfurt remains the country's main air hub (Redding, Sturm and Wolf, 2011[218]).

The discontinuity of space is also linked to different legal frameworks as well as cultural, language and other differences (Naveed and Ahmad, 2016[220]). A range of border-related inefficiencies generally stem from physical, institutional and cultural or social disruptions and tend to require different policy responses (Capello, Caragliu and Fratesi, 2018[221]). Because of the economic space discontinuity and due to the general remoteness from the markets in the central parts of the country, border regions often underperform economically (Capello, Caragliu and Fratesi, 2018[215]). The disruption effect of the borders can be even more evident in the case of unstable borders, where the disruptions become in a sense dynamic (Kitamura and Lagerlöf, 2019[214]). The negative effects of borders are regularly studied in the context of the disrupted

trade flows (Bacchiega, Minniti and Palestini, 2016[222]; Kashiha et al., 2016[223]) and knowledge flows (Naveed and Ahmad, 2016[220]), which are both linked to productivity performance, as already described.

The opposite, however, also holds – there are generally economic benefits of common economic space with unhindered flows of resources (Thirlwall, 1974[224]). Productivity can increase after borders were removed via a multitude of mechanisms ranging from increased competition to heightened demand and market size to greater availability of knowledge and technology (Capello, Caragliu and Fratesi, 2018[225]).

A proximity to a border often engenders a specific regional dynamics within border regions. The most able of them try and often succeed in developing compensatory mechanisms to counteract the suppressing border effects experienced by their economies. The success of the compensatory mechanisms, however, may depend on the factors beyond pure economy. For instance, the disruptions stemming from negative perceptions of people on the other side of the border may render compensatory mechanisms inefficient (Capello, Caragliu and Fratesi, 2018[215]) .

Agglomerations and agglomeration spread

When it comes to the spatial context, the link between urban agglomerations and productivity is perhaps most clearly established by both theoretical and empirical research. Agglomeration economies are the benefits that arise when people and firms co-locate (Glaeser, 2011[226]). The sources of agglomeration economies include technological spillovers, labour pooling, and intermediate input linkages (Marshall, 1890[227]) or, to put it simply, sharing, matching and learning (Duranton and Puga, 2004[228]).

The empirical literature finds a strong positive link between measures of agglomeration (usually population size or population density) and productivity of regions and firms. The early estimates by Sveikauskas (1975[229]) show a 6% increase in labour productivity for a doubling of the population, although these estimates were later challenged on the methodological grounds (Moomaw, 1981[230]; Ciccone and Hall, 1996[231]). More rigorous estimates, nevertheless, give a comparable magnitude of productivity increase, which ranges between 3% and 8% (Rosenthal and Strange, 2003[232]), or, according to the more recent estimates, between 2% and 5% (Combes, Duranton and Gobillon, 2011[233]; OECD, 2015[234]). Puga (2010[235]) provides an extensive overview of the evidence in support of the agglomeration economies.

When assessing the link between agglomeration and productivity, the total estimated effect consists of two components, the pure agglomeration economies (an increase in productivity because workers and firms become more productive in larger cities) and the selection effect (because initially more productive workers and firms choose to locate in larger cities). For instance, Ahrend, Lembcke and Schumann (2017[236]) estimate that the doubling of population in large (above 500 000 residents) metropolitan areas within the OECD is associated with 12% total increase in average labour productivity, which comes from both selection and agglomeration effects. This magnitude of the overall effect is generally in line with findings in the literature on urban scaling (Lobo et al., 2013[237]). In more detailed econometric specifications, which distinguish between the two mechanisms, the agglomeration productivity premium is within the 2-5% range (as noted above) and the remainder is accounted for by selection.

The *agglomeration* productivity effects accrue via several mechanisms. First, larger cities allow for better matches between employees and firms leading to a better performance (Venables, 2011[238]). Second, the higher productivity of metropolitan workers can be driven by learning-by-working in large cities. The productivity premium of the large-city employment experience is found to be larger for workers with higher initial ability. The premium also lasts even after workers leave the large agglomerations (de la Roca and Puga, 2017[239]).

At the firm level, Andersson and Loof (2011[240]) find that manufacturing firms located in larger regions of Sweden are more productive. The authors also discover the learning effects of being situated in larger urban areas. Harris and Moffat (2012[241]) look at the TFP of manufacturing plants in Britain. Their study

confirms that production facilities in larger cities tend to enjoy higher TFP levels, although there are also effects of broader regions within the country. Firms located in proximity are likely to learn from each other and to adopt successful strategies of their neighbours. For example in Spain, small new firms located close to incumbents with established export ties to certain countries are more likely to start exporting to these destinations (Silvente and Giménez, 2007[242]).

The productivity-increasing effects of agglomerated economies are not confined to the city boundaries. Dynamic cities often lift the economic performance of their (well-connected) surrounding areas ("hinterlands") via the so-called agglomeration spread effects. The effects are driven by the urban demand for goods, services and amenities of the rural areas and by the rural access to the urban markets (OECD, 2016[243]; OECD, 2018[244]).

Smaller cities and rural areas nearby large cities (or with fast and convenient connection to the large cities) are able to tap into the benefits of the agglomeration economies without actually being an agglomeration. The productivity performance of such places is higher compared to their more isolated counterparts. This phenomenon is called the "borrowed size" and is often found in many countries (OECD, 2018[244]). Aside from productivity performance, proximity to a city was found to have a positive effect on population growth in the TL3 regions across OECD countries (Veneri and Ruiz, 2016[245]) and in the US counties, although in the latter case the positive effect is evident only around smaller urban areas (Partridge et al., 2009[246]; Partridge et al., 2008[247]).

The agglomeration spread effects are only a part of the story. Proximity to cities can also exert a negative influence on the economic performance of nearby rural areas, which is more likely when adequate connecting infrastructure is absent. If congestion precludes urban residents from living and spending money in rural areas while also cutting rural businesses off urban markets, agglomeration backwash effects can prevail, as residents relocate to cities and rural businesses are unable to compete against their city-based rivals. In this case, the size of the nearby urban centre and its growth can suppress economic outcomes in the hinterlands[2].

Traditional and digital infrastructure

Investment in infrastructure is a common component of regional development policy. Infrastructure objects, such as highways, airports, communication networks and electricity grids, directly influence the operation of economic agents by facilitating the access to new resources and by increasing productivity of the existing ones. By their nature, infrastructure objects are nonexcludable goods. The shared use of the non-excludable goods can generate positive externalities, which in the urban context can give rise to the agglomeration economies (Eberts and McMillen, 1999[248]). The effects of infrastructure on local economy are, therefore, also related to the strength of agglomeration externalities they spur.

Quantifying the contribution of the infrastructure investment to economic performance is, however, a challenging task. Earlier studies on the link between infrastructure and productivity have traditionally focused on the aggregate investment in infrastructure often finding a substantial positive effect (Aschauer, 1989[249]; Aschauer, 1989[250]), but have been later widely criticized for the methodological approach (Gramlich, 1994[251]). Recent literature has instead shifted towards assessing the effects of specific infrastructural projects.

There is growing evidence that by reducing travel costs the transport infrastructure boosts productivity of local firms. For instance, Bernard, Moxnes and Saito (2019[252]) find that opening of a high-speed rail in Japan has increased productivity of local firms. Lembcke and Menon (2017[253]) find that expansion of a road network in Korea resulted in productivity gains, but only for the frontier firms. Within countries, a positive effect of infrastructure investment on productivity is reported by Banerjee, Duflo and Qian (2012[254]) for China and by Ahlfeldt and Feddersen (2018[255]) for Germany.

Although the magnitude of the estimated effects reported in these studies decays with distance, the impact of the infrastructure investments tends to spread beyond the targeted places. The positive effects of highways and railroads on growth of peripheral regions have been, for example, documented by Baum-Snow (2007[256]), Baum-Snow et al. (2017[257]) and Ahlfeldt and Feddersen (2018[255]). The crowding out of the economic activity in the peripheral regions, however, can also take place. For instance, Faber (2014[258]) concludes that the expansion of a road network in China reduced GDP growth in the non-targeted peripheral counties.

By facilitating the movement of people, the transport infrastructure can also influence firm location decisions. Studying the determinants of the headquarters' location choices across European urban areas, Bel and Fageda (2008[259]) find a strong support for the importance of proximity to international airports with intercontinental flight connections. Similarly, the proximity of airports is found to influence location decision of firms in Brueckner (2003[260]). More generally, by inducing the concentration of people and firms, the transport infrastructure can influence the distribution of economic activity in space (Redding and Turner, 2015[261]), determining the location of industries (Redding, Sturm and Wolf, 2011[218]) and cities (Bleakley and Lin, 2012[262]).

The telecommunications are another type of infrastructure with immediate impact on productivity. By reducing communication costs, the telecommunication technology allows for the expansion of markets and facilitates information exchange. The deployment of the telecommunication infrastructure is not uniform across time and space. Naturally, some places get access to the technology earlier than others, which may give these places an early advantage in reaping the benefits of cheaper information flows.

The broadband is one example of the telecommunication infrastructure directly related to space with potential gains to productivity. By providing firms with access to internet, the broadband enables the connectivity of local firms to the global markets thus extending the potential pool of customers and suppliers. Productivity gains can also arise thanks to a wide range of internet-enabled technologies which can, for instance, help firms to minimize transaction costs (e.g. remote communication services) and streamline management operations (e.g. customer relationship management). When it comes to the spatial context, the spatial variation created by the roll-out of the broadband infrastructure has been repeatedly shown to create substantial spatial differences in firm performance (Akerman, Gaarder and Mogstad, 2015[263]; DeStefano, Kneller and Timmis, 2018[264]) although the evidence is still mixed (DeStefano, Kneller and Timmis, 2018[264]; Bartelsman, van Leeuwen and Polder, 2017[265]).

Governance

The benefits of agglomerations often come with a number of challenges such as pollution, congestion and the issues of public health and sanitation (OECD, 2012[266]), which, in turn, can suppress productivity. An efficient governance structure can be a lever for enhancing productivity-boosting effects of agglomerations and for mitigating their negative consequences, although the rigorous literature on the links between governance structure and productivity indicators is scarce.

The urban governance structure usually differs in the level of fragmentation. A high level of fragmentation can improve public goods provision, at least in theory, via inter-jurisdictional competition and the availability of more choices for residents (Tiebout, 1956[267]). On the other extreme, a high fragmentation entails increased coordination costs where it could be difficult to find an efficient structure that ensures maximum gains in productivity and wellbeing.

To illustrate, Functional Urban Areas (FUAs), defined by the patterns of economic activity and interdependence (OECD, 2018[268]), usually do not coincide with administrative borders. Sometimes, FUAs can consist of more than hundred municipalities (OECD, 2013[269]). In the case of a pronounced spatial mismatch between administrative boundaries and the flows of economic activity, both vertical and

horizontal coordination of transportation networks or spatial planning, for example, becomes complicated, potentially decreasing economic prospects of a region via additional bureaucracy, congestion and a lack of appeal to highly skilled workers (Ahrend et al., 2017[270]).

Another disadvantage of a highly fragmented governance structure is the likely inability of local governmental units to recognize positive externalities at the FUA level (Pinto, 2007[271]). In general, policy areas with significant externalities, such as growth (Cheshire and Magrini, 2009[272]) or transport and land-use planning (OECD, 2015[273]) may suffer under more fragmented governance due to the increased coordination costs. The negative consequences of fragmented government structures can be felt beyond the economy. The wellbeing of residents in the fragmented urban areas can suffer due to the malfunctioning transportation systems, inefficient garbage removal, increased pollution and other failures of coordination (Ahrend, Lembcke and Schuman, 2016[274]).

The empirical work on fragmentation has shown both positive (Stansel, 2005[6]) and negative (Zhang and Zou, 1998[275]; Xie, Zou and Davoodi, 1999[276]) effects on economic performance. Cheshire and Gordon (1996[277]) argue that a limited number of jurisdictions with a close match of the highest tier authority to the FUA should increase the chances of forming a 'territorially competitive club', due to the smaller transaction costs and spillover losses. Cheshire and Magrini (2009[272]) examine this argument in Europe and find that the proportion of the functional region's population residing in the largest administrative jurisdiction is positively associated with economic growth. There is also evidence that the effects differ depending on the function of the government and along the urban-rural continuum (Ahrend and co-authors (2017[270])offer a brief overview).

The most relevant study in this context is a recent examination of the relationship between horizontal administrative fragmentation in city governance and the magnitude of productivity premiums across five countries (Ahrend et al., 2017[270]). The results suggest that FUAs with twice as many municipalities and no common governance body experience 6% lower labour productivity. This productivity penalty is reduced to 3% if a governance body is present.

Focusing on Italy only, Fadic and co-authors (Fadic, Garda and Pisu, 2019[278]) demonstrate that public administration efficiency at the provincial level boosts the labour productivity growth and the TFP growth of individual firms. The efficiency of the administrative, management and control functions as well as in the public transportation provision has the largest effects. In particular, if a province moves from the 25th to the 75th percentile in the public administration efficiency, firms on average are expected to 2.4% to their labour productivity growth and 0.4% to their TFP growth, which is a sizable increase both statistically and economically.

Notes

[1] The certain features of the terrain and climate, as well as the availability of natural resources can shape productivity performance of regions through heavily concentrated industrial structure. Many resource- and terrain-dependent industries are very capital-intensive. As a result, regions specialising in oil and gas extraction or those with significant presence of agricultural activities tend to be highly productive due to the technological retooling in the corresponding industries.

[2] For example in the US, employment growth in the largest cities (over 1.5 million residents in 1990) appears to stimulate wage and salary employment growth in the nearby smaller metropolitan counties, while the two types of rural regions in the country (rural and micropolitan) are unable to benefit from the growth. What is more, employment growth in largest cities suppresses self-employment growth in the nearby rural and micropolitan counties. In contrast, growth in small urban areas promotes total employment

growth in both types of nearby rural areas, whereas growth in medium-sized cities helps employment growth only in the micropolitan surrounding regions (Tsvetkova, Partridge and Betz, 2017[286]).

7 Interdependencies among productivity determinants

As follows from the literature overview above, productivity is driven by a plethora of factors at the national, sectoral and local levels. These factors are often interrelated and form a complex web of mutually dependent productivity drivers that shape productivity of a region both directly and indirectly.

The international literature has paid ample attention to the interdependencies among various "traditional" productivity determinants. For example, innovation and business churn both affect productivity. However, as shown by Foster, Grim, Haltiwanger and Wolf (2018[279]), the periods of rapid innovation in an industry are accompanied by intensive business entry. Thus, innovation, in addition to affecting productivity via multiple channels described above, has an additional indirect effect via stimulating business entry and related to it experimentation with production processes and an increased competitive pressure. In a related manner, innovation itself can be driven – at least in part – by a myriad of other factors.

Another example is the role played by MNEs in boosting productivity of host industries and countries. The degree of MNE penetration obviously depends on laws and regulations that delineate the freedom that multinationals can enjoy in doing their business. Given that the presence of MNEs is a delicate issue in many contexts, where international enterprises can be perceived both as heroes and villains of globalisation, designing efficient policies for the MNE attraction is not easy. At the same time, positive spillovers from MNEs are more likely if there are (technological) complementarities between multinationals and domestic firms in production processes.

Many of the interdependencies, however, crucially depend on the spatial dimension. For instance, for the MNEs to promote productivity of their host regions, the latter need to possess sufficient absorptive capacity. Likewise, the positive effects of innovative technologies in production depend on the quality of local human capital, which makes utilisation of advanced production processes possible and increases the likelihood of technology adoption.

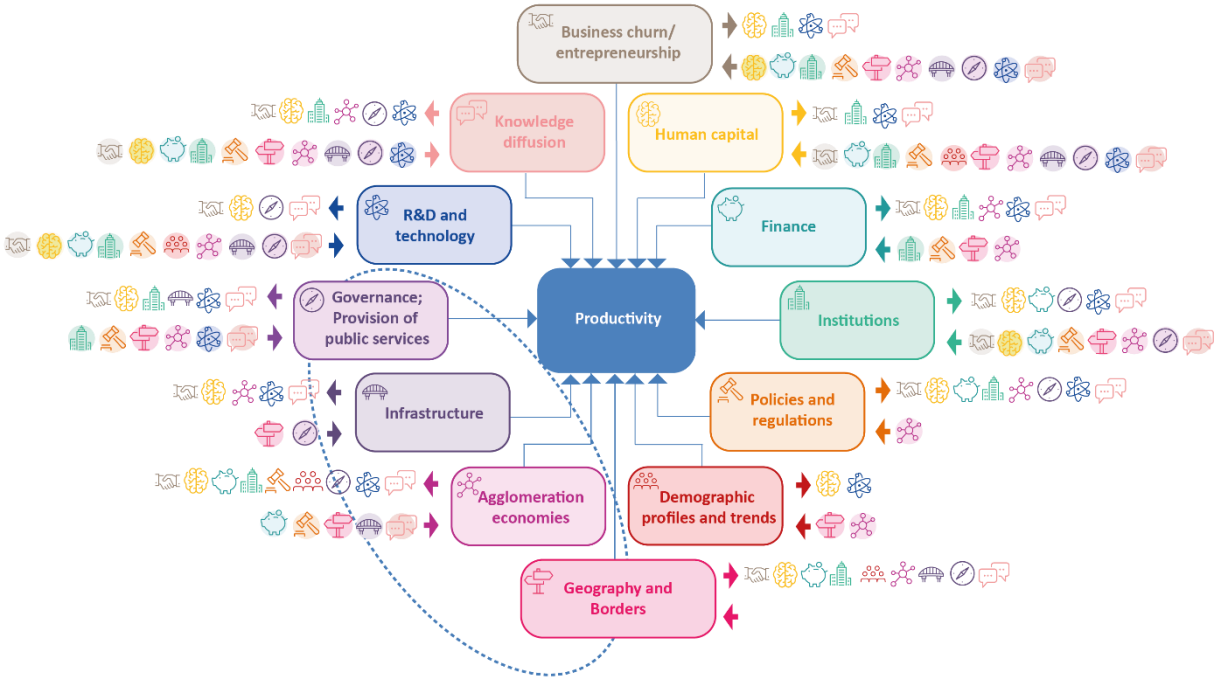
The academic research increasingly challenges the linear model of economic performance and instead gravitates to a systemic approach in which a dense web of local factors (institutions, regulations, networks, FDIs, MNEs, universities, human capital and others) work in tandem to promote or suppress innovation, entrepreneurship and other central indicators of economic vibrancy, which enhance productivity.

As an example, research universities, which are often the central players within regional innovation systems and local entrepreneurial ecosystems, can influence productivity of the nearby firms (by disseminating technologies, preparing qualified workers and other means), shape the stock of locally available human capital (by teaching and attracting high-skilled individuals to the area), intensify knowledge diffusion, R&D and entrepreneurship. An university can also contribute to the expansion of the local cultural amenities, formation of local networks and be a factor that attracts MNEs.

Figure 7.1 offers an overview of the interdependencies among the discussed productivity drivers. For every productivity determinant, the outward arrow points to a range of drivers, which the given determinant influences. The inward arrow, on the other hand, originates at the group of productivity drivers, which shape the given determinant. While the displayed relationships are quite multi-dimensional, the Figure is a

simplified representation of the productivity-driving dynamics. The figure omits entirely the underlying spatial factors, which, in turn, are also interdependent and affect the displayed productivity determinants and regional productivity both directly and indirectly.

Figure 7.1. The inter-linked nature of productivity determinants



Source: Own synthesis of the literature.
Note: The oval contour in the South-West corner encompasses the four determinants, which are mostly studied within the regional science literature and can be considered as “purely spatial” in nature.

8 The role of spatial dimension for policy complementarity

The detailed overview of the productivity drivers and of their interdependencies suggests that increases in productivity can result from a range of policies (many of them already in place) targeted at these determinants. It is well-established in the literature (mostly in the context of nations) that policy complementarities must be taken into account in order for policies to be efficient in achieving desired outcomes (Braga De Macedo and Oliveira Martins, 2008[280]; Braga de Macedo, Oliveira Martins and Rocha, 2014[281]; Combes et al., 2014[282]).

In theory, reforms aimed at removing distortions in the economy should affect all distortions proportionately in order to lead to an unequivocal increase in wellbeing. If distortions are removed at a varying pace, the wellbeing can decrease as a result of such "unbalanced" interventions. It has also been shown that if the reforms (the removal of distortions) are pair-wise complementary, the returns on doing one policy is always greater when another policy is already in place and the system becomes supermodular[1]. With certain (general) assumptions, this case generalises to any number of policy pairs (Braga de Macedo and Oliveira Martins (2008[280]) offer a more detailed overview and discussion).

At the international level, the changing nature of economic processes that are increasingly shaped by new technologies and a virtual space requires coherent trade, competition and taxation policies across international borders (OECD, 2019[283]). As overviewed in the previous subsections, the distortions of the international economic space, which hinder the flow of resources and fair competition, are usually detrimental to productivity performance of firms, industries, regions and countries in the long run. Productivity is not the only outcome that is promoted by clear, consistent and not burdensome regulatory regimes. According to the literature, other expected outcomes include enhanced business dynamism, knowledge and technology diffusion to name a few.

The national policies and economic conditions often determine the attractiveness of a country and its regions for the MNEs. For the regions to be able to reap the benefits from the presence of the MNEs within their borders, it is crucial to possess sufficient absorptive capacity in terms of own research and production activities, as well as the adequately educated labour force, which can be employed by the multi-national firms.

The importance of MNEs and GVCs for the development and growth of nations and regions brings another dimension of policy complementarities into focus. As argued by Crescenzi and Iammarino (2017, p. 111[82]), the complexity and the multi-level nature of the contemporary production processes requires "composite, diversified and tailored development policies based on modular combinations of public and private actions, from both local and global sources". The authors advocate for complementary interventions where, for example, the nature of support at the micro-level (e.g. training for individuals and firms) is selected based on the requirements and characteristics (e.g. industrial structure, etc.) of the regions.

In general, the range of the national productivity-enhancing measures is broad and is likely to have differing effects across the subnational regions depending on the local economic, social and demographic characteristics. At the very basic level, improving the educational systems to more adequately address the needs of the changing economies and of the new production processes is fundamentally important. Many

skills become obsolete or are replaced with new technologies, while different (or new) sets of skills come into high demand. Ensuring that the educational systems keep pace with these changes is imperative for sustaining the high living standards and the growing (or at least non-shrinking) share of the middle class in the future.

Beyond the primary and secondary education, universities continue to change their agenda to incorporate community outreach and local economic development functions in addition to the traditional education and research. Higher educational institutions are perhaps best positioned to address local and regional human capital needs determined by the industrial structure and other characteristics of their host regions.

Universities and other educational institutions can also contribute to an array of productivity-enhancing activities at both firm- and regional levels via, for example, training, technology diffusion and attracting higher value-added industries. Continued collaborations between universities and local policy-makers can prove fruitful for designing tailored policies that adequately address local challenges and are based on inputs from stakeholders at various levels.

Healthy competition policies and regulations are equally important. Here, a level field for economic activities by all types of firms and industries (small and large, well-established and new) is needed. The fair competition encourages improvements of the managerial and production routines, stimulates development and implementation of new technologies and practices and accelerates exit (with subsequent re-use of resources) of the less efficient companies.

The literature shows that for policies to be effective, educated and holistic design needs to be coupled with competent implementation. For instance, market deregulation in India had intended effects only in the absence of restrictive labour market regulations (Aghion et al., 2008[284]). In a similar vein, Buccirossi et al. (2013[106]) argue that the positive effect of the competition policies on productivity growth is strengthened in countries with efficient law enforcement institutions.

At the subnational level, the geographically unequal effects of policy measures, both space-blind and regional, point to the central role played by the spatial realities in the ability of policies to be synchronised and to enhance each other. The spatial dimension is the cornerstone of the modern approach to the regional development policies. As outlined by Garcilazo and co-authors, the approach is based on the three main principles: (1) identifying regional assets; (2) capitalising on policy complementarities for the maximisation of policy impacts on the economy and (3) utilising multi-level governance arrangements for coordination of actions and objectives across various levels of government (Garcilazo, Oliveira Martins and Tompson, 2015[204]).

Policy complementarities are particularly important in situations where the effects of multiple factors on regional economic performance is nonlinear. The literature only now starts to systematically study these dynamics since the traditional parametric specifications often are ill-equipped to capture the shadow and threshold effects, heavy and multiple nonlinearities. Etc. In the cases with a threshold dynamics, for instance, a sufficient intensity of all involved factors must be in place for the desired outcomes to materialise. With respect to policies, this means that for a policy effort to be successful, it may need to be devised as a bundle of interventions, which may or may not be within the responsibility of the same ministry or administration department.

Charlot, Crescenzi and Musolesi (2015[285]) provide an illustration. The authors devise an augmented regional knowledge production function where the traditional factors, such as R&D and human capital, are inputs. They demonstrate that in the European regions, the expenditures on research and development should be at 2-3% of regional GDP to generate maximum effects on patenting intensity. For the human capital to have any effect, at least 20% of population should possess tertiary education. Most importantly, expenditures on R&D produce visible results only if a region has a sufficient concentration of highly educated residents. As a result, efforts to expand the share of population with higher levels of education may be the necessary condition for other policies to be successful.

Overall, the success of policies aimed at enhancing local productivity and alleviating regional inequalities can depend on a wide range of concurrent programmes working in synergy. Among the examples of productivity-enhancing policy interventions are programmes that facilitate best practice sharing and technology diffusion; training, retraining and better employer-employee matching services; ensuring that adequate infrastructure (including high-speed Internet access) is in place; facilitating access to financing for young, small and otherwise disadvantaged companies as well as digital governance to name just a few.

[1] If for every policy pair in place, the returns on one policy are enhanced by the presence of another policy, the system (the full set of policies) is supermodular. In this case, policy changes would reverberate through the system leading to the improved outcomes automatically even if the removal of distortions is not proportional. In reality, the supermodularity of the system of policies can be achieved only if there are no policy pairs, in which the effects of one policy negate the effects of another.

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