Economic Research Working Paper No. 57

The Geography of Innovation:
Local Hotspots and Global Innovation Networks

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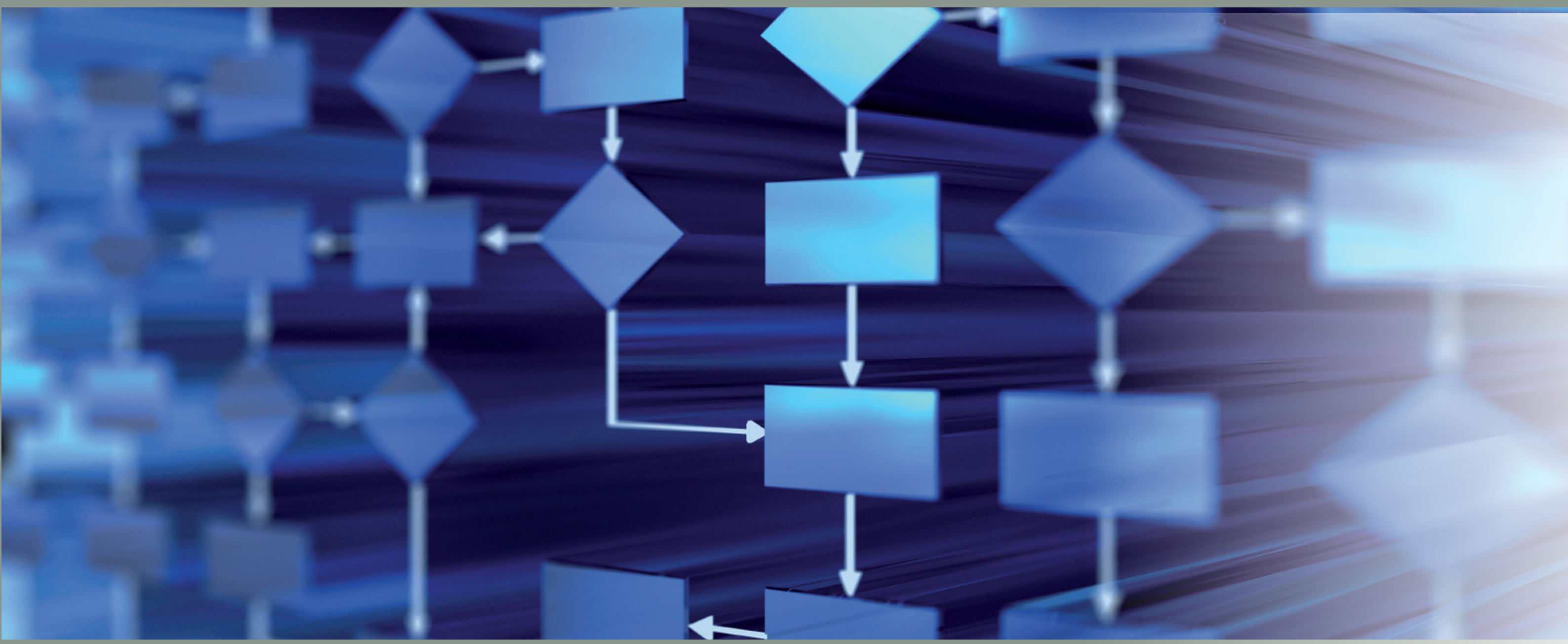

November 2019

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Abstract

Through successive industrial revolutions, the geography of innovation around the globe has changed radically, and with it the geography of wealth creation and prosperity. Since the Third Industrial Revolution, high incomes are increasingly metropolitan, leading to a renewal of inter-regional divergence within countries. These metropolitan areas are also hotbeds of innovation. At the same time, global networks for the production and delivery of goods and services have expanded greatly in recent decades. The globalization of production is mirrored in the globalization of innovation. The paper argues that the emerging geography of innovation can be characterised as a globalized hub-to-hub system, rather than a geography of overall spread of innovation. Although much attention has been given to explaining the rise and growth of innovation clusters, there is as yet no unified framework for the micro-foundations of the agglomeration and dispersion of innovation. In addition, there appear to be strong links between growing geographical inequality of innovation and prosperity, particularly within countries. This is particularly relevant in the context of declining overall research productivity, which could be driving growing geographical concentration. All in all, there is a rich agenda for continuing to investigate the relationship between the geography of innovation, economic development and income distribution.

Keywords: Geography of innovation, clusters, networks, inequality

JEL codes: O33, R12

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Acknowledgments

The authors would like to thank Intan Hamdan-Livramento, Ernest Miguelez and Julio Raffo and for their comments and suggestions, as well as other staff of the World Intellectual Property Organization (WIPO) who commented on earlier drafts. We would also like to thank Frédérique Sachwald for her discussion and other workshop participants at WIPO in Geneva in 2019.

All errors remain our own.

List of abbreviations

GIN – Global Innovation Network
MNE – Multinational Enterprise
R&D – Research and Development
GVC – Global Value Chain

1 Introduction: The intertwined geographies of innovation and economic development

Technological innovation – or more widely the generation of new knowledge that can be applied to improve total factor productivity, and the quality and variety of outputs of the economy –makes the most important contribution to economic growth and per capita income. Maddison (2001) showed that from roughly the year 1000 to about 1820, there was little progress in world per capita income, in spite of only moderate population growth, with the world mostly stuck in a Malthusian cycle of resource scarcity without sustained productivity growth. The last two hundred years, however, have witnessed the greatest growth of both human population and economic welfare in recorded human history. This short 200-year period began with the first industrial revolution, and has continued through successive major industrial revolutions, each defined by major technological shocks across groups of related fields of endeavor (WIPR, 2015).

This empirical picture is now interpreted theoretically in the form of modern growth theory, from Kaldor through Solow to Romer, and their offshoots, which identifies the unique nature of innovation as a source of potentially unlimited productivity growth. New knowledge is, broadly speaking, a positive externality for the economy, which has a non-excludable, shared, recombinant and cumulative character, giving rise to overall increasing returns to both research and development, as well as practical innovation (Romer, 1986).

There are many outstanding debates about precisely why this period came about when it did, but there is widespread agreement that it was the belated result of a sharp uptick in evidence-based scientific thinking that occurred in Europe in the 1600s, transforming an irregular practice of technological advance throughout human history into an increasingly systematic and cumulative system for developing new theoretical knowledge and expanding its domains. It was therefore, only a matter of time before science would beget systematic application in the form of a productivity revolution, which came in the form of the First Industrial Revolution, centered on textile mechanics and water and steam power (Acemoglu, Johnson, and Robinson, 2005; Mokyr, 2005). "In 1750 more than 50 percent of the world's industrial output was produced in China and India, compared to some 18 percent in Western Europe. The following eighty years saw the Industrial Revolution, with western Europe's industrial output more than doubling and that of the United Kingdom increasing by a factor of 7." (Crafts and Venables, 2003, p.325).

These twin revolutions – scientific and industrial or technological – however, did not take place evenly across the world. They introduced a distinctive developmental hierarchy to the world economy, beginning in the late 18th century, known as the Great Divergence (Pomeranz, 2000). This term refers to the gap that opened up in per capita income between a set of European countries and other leading economies of the time, notably China and India. The geography of innovation of the First Industrial Revolution enabled Europe to rise in the global hierarchy of incomes and development, and within Europe, a selected set of regions and cities constituted the "European core."

Since then, successive major industrial revolutions have also had distinctive geographies. The Second Industrial Revolution, which was broadly electro-mechanical, witnessed the entry of North America into the high-income club of the world, while broadening the industrialized regions of Europe. But, significantly, it also had different geographies within the major regions of the world – by which we mean the cities and regions – from the First Industrial Revolution. In North America, New England had been the heart of the First IR, but the Middle-Atlantic states and the Midwest were the heart of the Second IR. There was not perfect overlap between the countries, cities, and regions that were the core territories of the Second Industrial Revolution and the First, and some former core regions of the First fell into economic decline whilst others emerged, all of this occurring in the late 19th and early 20th centuries. Moreover, the Second IR placed North America at the heart of the world economy.

More recently, a Third Industrial Revolution has occurred, with a Fourth possibly here or on its way (Baldwin, 2016). The Third IR broadly involves digital technologies, life science and biological technologies, financial engineering, and significant breakthroughs in transport and logistics. It arose in the 1970s and 1980s, corresponding also with the present period of globalization, as reflected in major increases in global trade and investment flows. The geography of economic development in this period has undergone some significant changes. First, there has been a spread of development at a global scale, starting with a set of rapidly developing Asian economies that are now in the high income group, including South Korea, Taiwan and Singapore. Subsequently, a set of large emerging economies has risen into the global middle-income core, with China the largest of them. This expresses a certain spreading out of global development. At the same time, without China, the structural hierarchy of global per capita incomes by country has not converged over the past few decades, because for the most part, the high-income countries have succeeded in reproducing their position in the global income hierarchy through sustained innovation and productivity improvements (Bourguignon, 2017; Milanovic, 2010; Sala-i-Martin, 1997). Northeast Asia, from Japan through Korea and China, is a highly innovative part of the world today, corresponding to its emergence as the third great pole of the world economy.

The reason we have introduced this paper on the geography of innovation with a perspective on the geography of economic development as a whole, and its unfolding and changes over time, is that the geography of innovation largely tracks the geography of development and has an intimate mutually causal relationship to it. As such, understanding changes in the geography of innovation is a key entry point into understanding the emerging geography of economic development as a whole.

1.1 Framing the Geography of Innovation in the 21st Century: Global Spread and Urban Concentration

One prominent feature of the geography of economic development that is common to both successful emerging economies and high-income ones: the geography of high incomes is increasingly metropolitan around the world, reflecting a renewal of inter-regional divergence within countries. Skills and high incomes flow increasingly to metropolitan areas, though somewhat selectively, with some older metropolitan areas never having recovered fully from losses due to deindustrialization. Generally speaking, but not exclusively, large metropolitan areas are increasing their distance to other regions in terms of income. These metropolitan areas are also hotbeds, or agglomerated ecosystems, of innovation. Thus, the emerging world geography of innovation is, like the world geography of development, one of *concentrated dispersion* (Ernst and Kim, 2002). The landscapes of knowledge creation, diffusion, adoption, investment, and appropriation are uneven at both the inter-national scale and the interregional (or subnational) scale. For the sake of clarity, let’s consider the two main categories of knowledge creation and knowledge flows or diffusion. Why would knowledge creation be unevenly distributed? Knowledge creation itself is only partially understood, but at a minimum, involves elements ranging from formal R&D, education, institutions such as property rights, investments, and institutions that reward experimentation and risk, as well as those helping actors to build on tradition. All of these contributors to knowledge creation are unevenly distributed at inter-national and interregional scales.

Knowledge flows, while expanding globally at an impressive pace, do not flow evenly across landscapes. The actors and systems who make knowledge flow range from individuals to firms to governments and research establishments, but may also include structured ensembles of these actors in the form of, for example, Global Innovation Networks (henceforth GIN), ad hoc firm or research collaborations, or crisscrossing overlaps between local innovation systems tied together through networks of scientists, entrepreneurs, workers, or policymakers. The constituent elements of these intricate network structures are not evenly distributed, hence flows have a distinctive geographical pattern and biases.

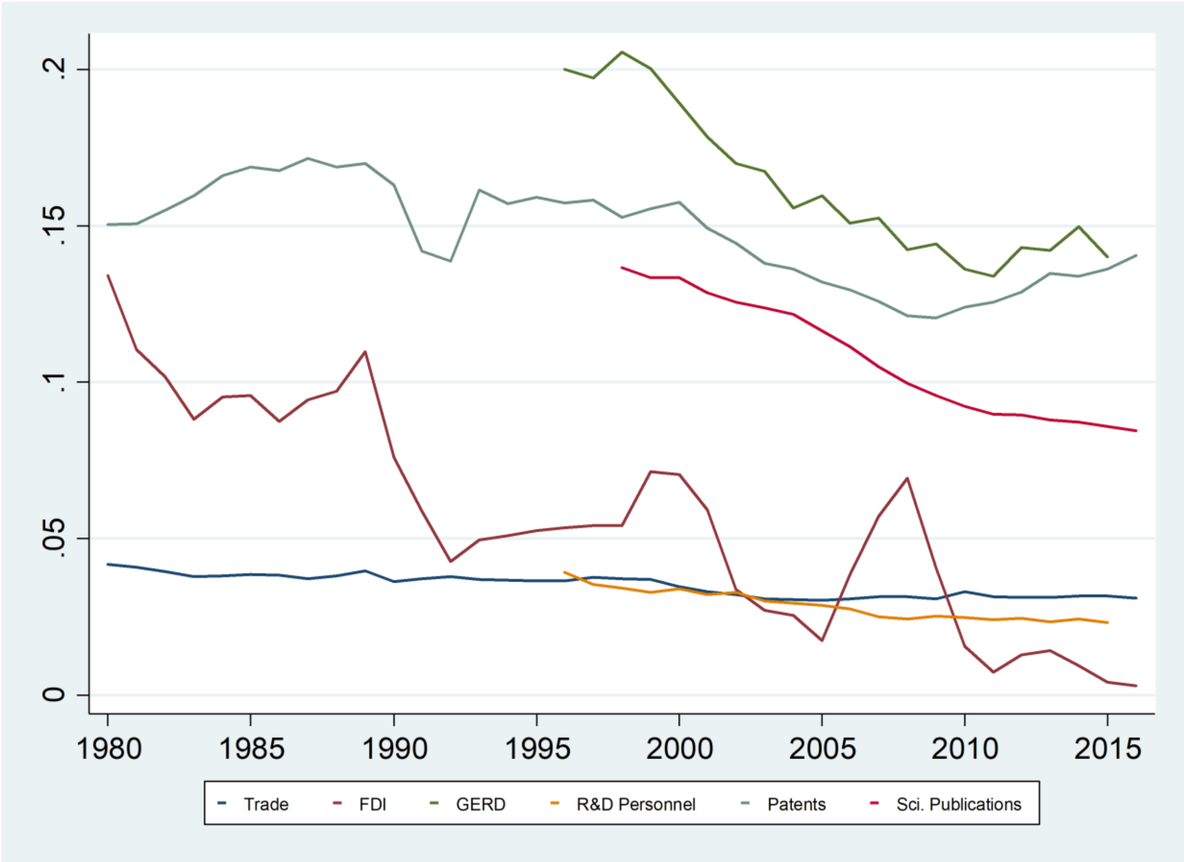
Knowledge benefits economies and specific sets of actors when it is appropriated economically, through production or property rights or both. Knowledge appropriation or use also seems to be expanding around the world, but through uneven geographical distribution of the ability to apply it and appropriate its benefits. Appropriation and production of knowledge are not identical, in terms of organization, agents, or their geographies. Hence, in tracking the geography of innovation, its relationship to appropriation must always be carefully problematized.

In the following two sections, we first consider how these processes are leading to increased dispersion at a global scale, principally through GINs of firms, researchers, and entrepreneurs, but also through the rise of innovation creation centers in more places around the globe. We then turn the tables to show that the same processes of creation, flow, investment and appropriation are still reinforcing global innovation-economic hierarchies in some ways, and especially how they are concentrating innovation in geographical hotspots, most of them metropolitan. Ultimately, we shall see that innovation is both spreading and concentrating, and that the feedbacks – in terms of knowledge creation and economic appropriation -- between spread and concentration are multiple and sometimes counter-intuitive.

2 The spread process: Global innovation networks

In recent decades, global networks for the production and delivery of goods and services have expanded greatly. The previous globalization from 1870 to 1914 was overwhelmingly based on classical Ricardian trade patterns of inter-industry exchanges of basic commodities or different final goods. The current globalization, by contrast, has a much higher proportion of intra-industry (or two- way, i.e. within global value chains) exchange of both components and final goods. Prior to 2000, most of such intra-industry trade took place among the Global North countries, but since then it has increasingly concerned the relationships between emerging market economies and the rest of the world. Moreover, global production networks often involve multiple or circular trade, with exports wrapped into subsequent outputs and ending up as imports, blurring the lines between foreign and domestic production. The current globalization, in other words, involves intricate forms of interdependency not just between economies as a whole, but inside the most delicate plumbing of the economic system, within and between firms and industries. This is also true of the plumbing of innovation, which is both a consequence of global productive integration and, increasingly, a cause of it.

Figure 1 – Hirschman-Herfindahl Index for selected economic and innovation indicators



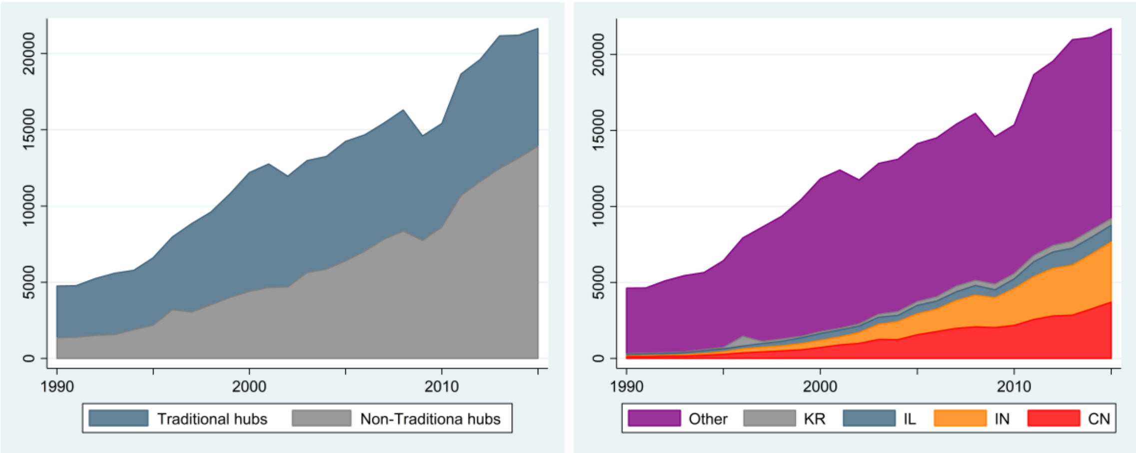
Source: World Bank, UNESCO, WIPO and Clarivate (2019). Notes: Trade = exports constant US dollars, FDI = inward foreign direct investment flows, GERD = gross expenditure in research and development (R&D), R&D personnel = human labor in R&D activities, Patents = foreign oriented patents, Sci. Publications = Scientific publications in the Science Citation Index Expanded, Web of Science; FDI series has a MA(3) filter

2.1 Foreign Direct Investment and the Emergence of Global Innovation Networks

Mirroring the increasing globalization and complexity of production systems is a growing dispersion and complex plumbing system for knowledge production. As Archibugi and Iammarino (2002, p. 100) put it, the globalization of innovation "thus comes to be the zip between the two fundamental phenomena of modern economies: the increased international integration of economic activities and the rising importance of knowledge in economic processes." A GIN may be defined as "a horizontal network driven by knowledge-seeking" (Barnard and Chaminade, 2011). GINs are brought about largely through the internationalization of corporate R&D, part of which is achieved through foreign direct investment. Hence, in understanding GINs, a great deal of research has focused on multinational enterprises (henceforth MNE).

The internationalization of corporate R&D plays a key role in this context with MNE international affiliates gaining more autonomy and becoming (where the right incentives are in place) more embedded in regional and local innovation systems. Global patenting is increasingly the results of the collaboration of large teams operating within the organizational boundaries of MNEs: a significant share of Chinese and Indian patents at the USPTO are the results of collaborations of this type (Branstetter, Li, and Veloso, 2014). Increasing autonomy of international affiliates also means that the choice of the specific (subnational) location becomes more important and driven by a wider range of factors other than costs (Cantwell, 1995). Characteristics of the regional innovation system and institutions are particularly important for attracting foreign investment in innovation and technological operations (Cantwell and Iammarino, 2003; Iammarino and McCann, 2013) and become relevant factors to attract investments at more advanced (and knowledge-intensive) stages of Global Value Chains (Crescenzi, Pietrobelli, and Rabellotti, 2014). While new information and communication technologies are generally thought to be driving forces behind greater globalization, the effects on individual firms can be more nuanced. ICT is indeed a decentralizing force, but it can result both in more or less autonomy given to plants abroad and foreign affiliates (Bloom, Garicano, Sadun, and Van Reenen, 2014).

Figure 2 US company patents with offshore inventors from Triad versus newer innovation areas, 1990-2015

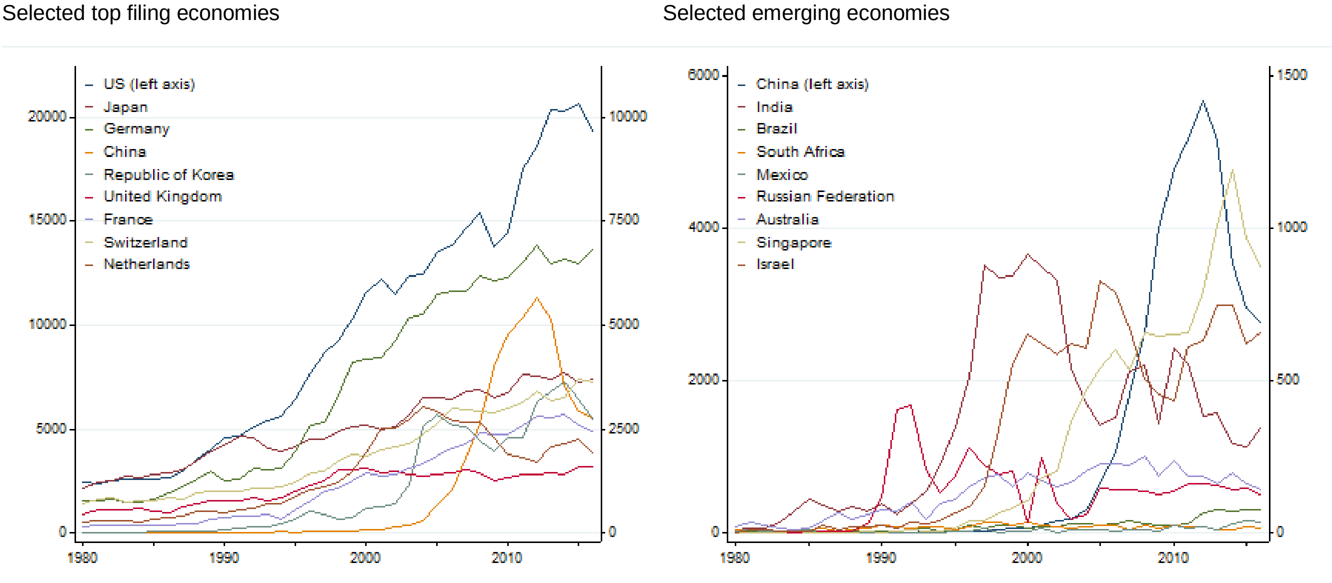


Source: WIPO Statistics Database. Notes: traditional hubs as defined in Branstetter et al. (2018).

Cantwell (1995) describes the process of internationalization of R&D by MNEs starting from the 1960s. MNEs from the US and Western Europe, particularly France and Germany, increased their share of R&D activity undertaken abroad from initially low levels. In smaller European countries such as the Netherlands, Belgium and Switzerland, but also the U.K., this share was already relatively high during the 1960s. In contrast, internationalization of Japanese MNEs only progressed slowly during the 1960s and 70s. Among the main motivations to internationalize R&D activities are shorter times to bring products to market (e.g. von Zedtwitz and Gassmann, 2002), access to talent as well as cost advantages (e.g. Lewin, Massini, and Peeters, 2009), and tapping into localized areas of technological excellence (e.g. Cantwell and Janne, 1999).

There is also evidence that intra- and inter-firm offshoring of R&D increases corporate innovation performance (Nieto and Rodríguez, 2011), and that international and local R&D collaborations affect product innovation differently for MNE affiliates and domestic firms (Un and Rodríguez, 2018). However, while the internationalization of R&D by MNEs is growing rapidly, most businesses still exhibit substantial home bias in their technological activities. Economies of scale and scope, coordination costs and embeddedness within the home country/region innovation system all result in more spatially concentrated corporate R&D activities than might be expected from otherwise highly internationalized activities of businesses (Belderbos, Leten and Suzuki, 2013).

Figure 3 Company patents with offshore inventors by selected company origins, 1980-2016



Source: WIPO Statistics Database. Notes: data for 2016 might be incomplete due to truncation.

International dispersion of innovation follows patterns of the global division of labor, as innovation activities pushing the technology frontier take place in (relatively few) established centers of excellence, whereas more routinized research activities take place in emerging economies. For example, some Central and Eastern European countries, such as the Czech Republic, Hungary and Poland, have experienced growth in their innovation activity and inflows of FDI. However, this tends to be in *older* industries, such as metallurgy and energy, which have relatively lower value added (Krammer, 2009).

Reversing flows of FDI further benefit established innovation centers. Emerging market MNEs are increasingly using outward FDI to expand their market reach and to capture strategic assets such as technologies, skills, commercial knowledge and brands. Local technological competences are only important for attracting emerging market FDI if the prospective subsidiary will engage in technology intensive activities (Crescenzi, Pietrobelli, and Rabellotti, 2016b). Chinese OFDI is growing rapidly, notably since the financial crisis, which Chinese businesses survived relatively unharmed (Davies, 2010).

From the mid-20th century until the the Great Recession beginning in 2009, technological activity was steadily internationalizing, with new countries emerging in the international system of innovation (Athreye and Cantwell, 2007). More recently there is some evidence on the selective reshoring of some key activities back to the home countries (Bailey and De Propris, 2014; De Baker, Menon, Desnoyers-James, and Moussiegt, 2016). At the same time, the post-recession period sees growing articulation of value chains beyond national borders, involving an increasing share of intra-firm trade flows (Cadestin, De Backer, Desnoyers-James, Miroudot, Ye, and Rigo, 2018; UNCTAD, 2015).

In the deepest form of internationalization today, GINs are integral parts of developed multi-layered Global Value Chains (henceforth, GVC. “The value chain describes the full range of activities that firms and workers perform to bring a product from its conception to end use and beyond. This includes activities such as design, production, marketing, distribution and support to the final consumer.” (Gereffi and Fernandez-Stark, 2011, p.4). Therefore, GVCs link a complex and diverse variety of actors that perform and coordinate a wide range of activities, both local and international (Crescenzi, Harman and Arnold, 2019b; Frederick, 2016). Although emphasis is often placed on the manufacturing component, services are crucially important elements of GVCs both in terms of intermediate and final demand (Gereffi, 1999). In the dominant governance mode of GVCs – distinguished in the literature in "buyer-driven" and "producer-driven" value chains (Gereffi, 1994) – MNEs play a special role as key GVC coordinators that establish multiple asymmetric linkages with varied business partners, depending on the segment of the value chain (Ponte and Sturgeon, 2014). From this standpoint "FDI location decisions can be seen as the key way in which MNEs can 'touch down' to geographic space and link up 'places' through GVC connectivity" (Crescenzi et al., 2019b, p.11).

Geographical and sectoral innovation system conditions are particularly important as drivers for the most sophisticated and high-value-added GVC stages, such as R&D, design or advanced business services (Alcácer and Chung, 2007; Chidlow, Salciuviene, and Young., 2009;). The off-shoring of R&D activities – as part of the expansion and re-configuration of GVCs - has created new inter-connected architectures of innovation and research (Massini and Miozzo, 2010; OECD, 2011; Schmitz and Strambach, 2009) as well as new co-location patterns with production activities. This has offered new opportunities for regions and cities to link up to different parts or functions of GVCs inw ays that promote economic upgrading and innovation (Crescenzi et al., 2019b). At the same time GVC participation is a challenge for weaker regions, given the risk of lock-in into low-value added and low-innovation activities. The spatial unevenness in GVC participation and embeddedness generates new core-periphery patterns in the global geography of innovation. However, comparable evidence on knowledge and innovation drivers of regional integration in GVCs at the subnational level remains thin (Crescenzi et al., 2014; Crescenzi et al., 2019b).

2.2 Firms: embedded and home-oriented, or a force for dispersion?

One of the key classical debates about multinational corporations was whether they were territorialized and highly attached to their home country, or whether somehow they were dis-embedded, simple articulators of a global chain of activities with little attachment to home territory (Vernon, 1979). MNEs are clearly key actors, as we argue above, in the generation of GINs and GVCs. In this respect, they can be considered key agents of dispersion, but they also do so from a position of high levels of embeddedness in their national economies, and usually in specific regions within their countries of origin. They do this because they use GINs as ways to acquire knowledge and deploy knowledge, strengthening their performance at home and abroad.

Turning this question around to focus on regions, it means that key knowledge-generating territories around the world are usually both home to key firms that construct and participate in GINs, but they are also very likely to be hosts for foreign firms wishing to get access to their knowledge-generating ecosystems, talent pool, and researchers. Agglomeration forces have attracted MNE activities – especially high-value added ones – to particular locations in both advanced and emerging economies, thus making the *geographical destination* of MNEs progressively less dependent on purely cost-based and relative endowment considerations (Iammarino and McCann, 2018). Mostly intangible location advantages are highly concentrated within specific regions, cities and local systems, and contribute to enhancing firm-specific ownership-advantages, which in turn strengthen those of the many locations where the MNE is present. Connectivity emphasizes the degree of two-way (inward and outward) openness of regions, and also of firms and actors there located, in terms of many behavioral and organizational dimensions of knowledge networks (Crescenzi and Iammarino, 2017). The simple nation-based *host-home* dichotomy largely applied in the academic literature to the MNE question therefore becomes less useful in relation to knowledge flows. Indeed, core regions are those subnational places where *host* and *home* overlap to a great extent, and the direction of such flows is eminently bi- or multi-lateral (Iammarino and McCann, 2018).

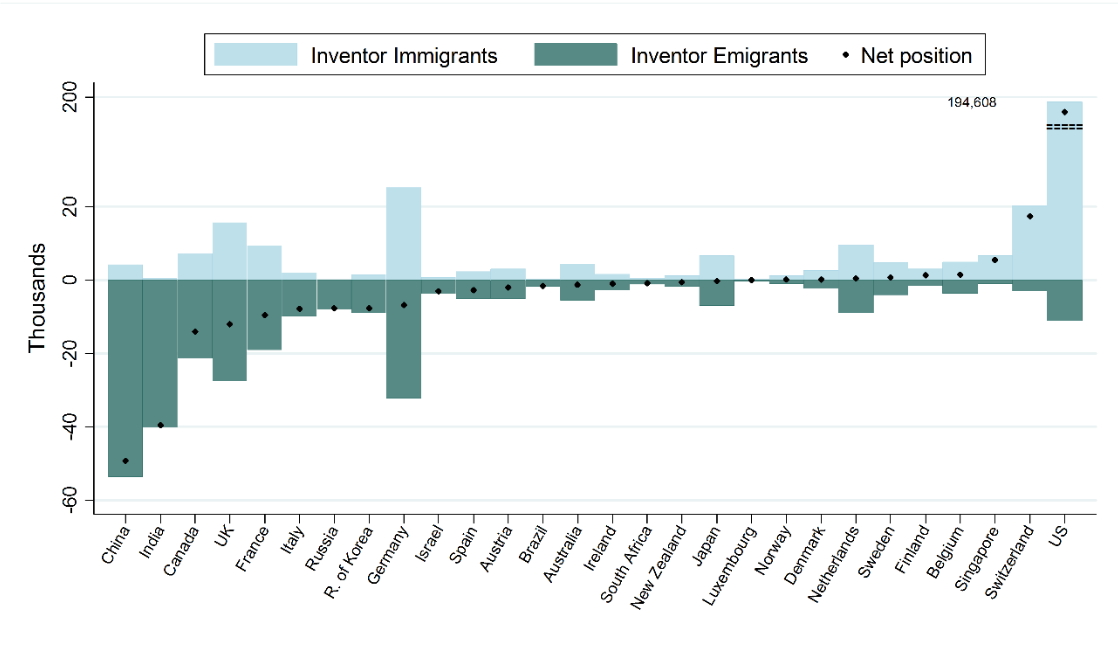
2.3 People: labor, scientific and entrepreneurial mobility and collaboration

There are other dispersion forces, notably labor mobility and knowledge networks. These may work through MNEs but may also be in the form of collaborations existing outside them. MNEs and highly skilled migrants benefit from, but also stimulate GINs (Breschi, Lissoni, and Miguelez, 2017).

The international and inter-regional mobility of skilled innovators is a key feature of the contemporary innovation environment. This mobility may positively stimulate the international dispersion of innovation by becoming a key "glue" in GINs. The mobility of people is most commonly determined by individual preferences to relocate, or through firm decisions to relocate workers either through setting up of foreign subsidiaries or increasing the workforce in pre-existing subsidiaries; these are materialized through FDI. Establishing networks can facilitate collaboration and the sharing of knowledge and ideas. Networks and pipelines feature the mobility of knowledge through people (Agrawal, Goldfarb, and Teodoridis, 2013; Breschi et al., 2017) and firms (FDI). Saxenian (1999) explores the interaction of people and investment networks through the mobility of skilled Chinese and Indian entrepreneurs in Silicon Valley. She explains how skilled workers come to Silicon Valley and acquire human capital and experience, and become integrated into networks in Silicon Valley, whilst continuing to maintain links in their countries of origin. This leads, for example, to Taiwanese engineers coordinating activities between Silicon Valley technology producers and the manufacturing and design expertise in the Hsinchu region. Consequently, *"The new immigrant entrepreneurs thus foster economic development directly, by creating new jobs and wealth, as well as indirectly, by coordinating the information flows and providing the linguistic and cultural know-how that promote trade and investment flows with their home countries."* Saxenian, 1999:.74-75)

As skilled Chinese and Indian entrepreneurs move around, they engage in sharing knowledge, leading to a 'brain circulation'. By drawing on their networks, they seem to be able to facilitate investments into new business ventures, highlighting the co-movement of networks and FDI channels.

Figure 4 - Inventor migration by country of origin and destination, select economies, 2004-2012



Source: Miguelez et al (2013). Notes: data refer to pairs of inventors and PCT applications.

The global diffusion of knowledge does not take place through random mobility of people, of course, but through their mobility between places in which they are likely to have the right kinds of interactions for innovation. This points to a possible geographical concentration effect that could be induced or reinforced by labor mobility. The global mobility of knowledge is a story of local interactions within regions and extra-local interactions across pipelines. At the local level are processes that link agents to one another, embedding them in localized networks (Capello and Faggian, 2005; Maskell and Malmberg, 1999). Embeddedness refers to the strength, type, quality and breadth of ties within the network, which determine "diffusion of knowledge and enhance(s) collective learning in clusters" (Giuliani, 2007, p. 140). These networks serve not just as means of dispersion and mobility, but as key points of attraction for the skilled, who can reap learning and experience premiums by being in the geographical hotspots of where networks are deep and their keys nodes are centralized (De la Roca and Puga, 2017). The ability to acquire more experience and improve skills is considered to be one of the main reasons why the skilled continue to move into the most expensive cities today, in spite of their high costs of living, contributing to the rapid growth in geographical differences in the wages of the skilled (Autor, 2019). This picture is complemented by evidence that both international and inter-regional brain drain is at a very high level today (Breschi, Lissoni and Tarasconi, 2014; US Congress, 2019).

All in all, then, labor mobility is a double-edged sword from the standpoint of dispersion and concentration of innovation.

2.4 Other forces that can influence the spread of innovation: the public sector and innovation systems

The global spread of innovation is not only due to the advent of GINs and the flows of knowledge through them, and the role of MNEs based in the Global North, but rather to innovation strategies and policies that succeeded in building world-class innovation policies in a set of formerly middle-income economies. These include South Korea, Taiwan, Singapore, and Israel, and – with the appearance of leading innovation clusters in them – China and India (Amsden, 2001; Wade, 1990). The concept of National Innovation System (Freeman, 1987; Lundvall, 1992; Nelson, 1993) – mentioned above – was mobilized to refer to the interlocking set of institutions, investments, strategies and practices that drive the innovation patterns and the industrial specializations of countries down particular pathways. Originally applied to the advanced countries to investigate these issues, it was subsequently extended to the developing world (e.g. Lundvall, Joseph, Chaminade, and Vang, 2009) as a way of thinking holistically about the network structures of innovation systems and how they have been shaped by the successful recent entrants into the top ranks of global innovators. Stated more simply, the spread of innovation globally seems likely to be due to the spread – difficult and uneven, of course – of successful National Innovation Systems.

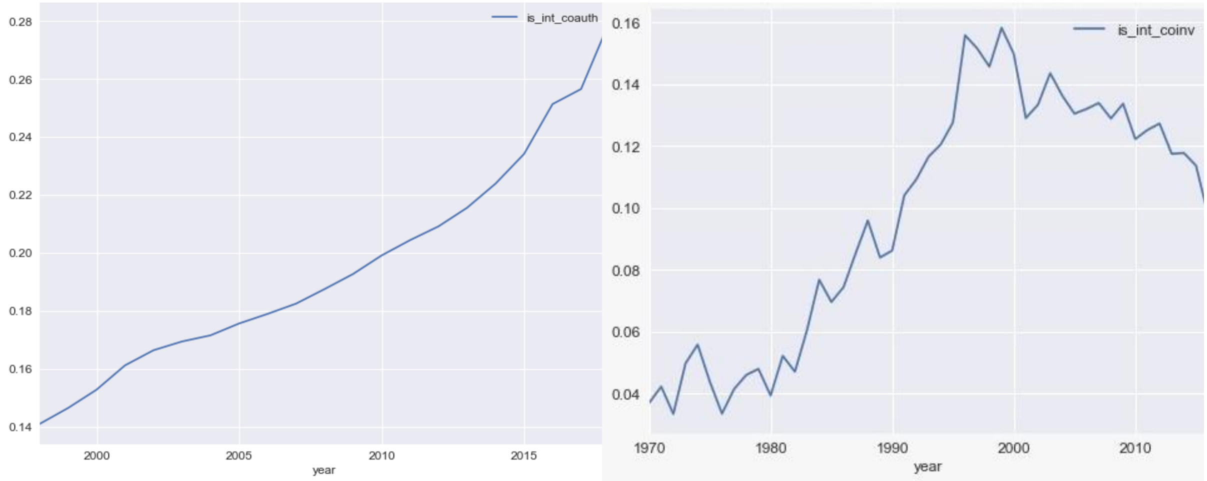
A common feature of any innovation system is that market forces of agglomeration are not the only factor shaping the geography of innovation. The public sector, as well as third sector and academic institutions are also key actors that shape the innovativeness of countries and regions. While public R&D spending is declining in advanced countries (Filippetti and Archibugi, 2011; Mazzucato, 2015), R&D in emerging economies is driven by public investment). In advanced countries, there are also measurement issues around the full public contribution to innovation, as an increasing share of public funding is channeled through universities, which may be public or private institutions.

Deliberate public sector approaches to innovation are motivated by a variety of different circumstances. In some countries and regions, stagnating productivity growth has stimulated a revival of industrial policy. As noted above, in many of the most successful emerging economies today and in the "star" former middle-income economies, industrial policy with a strong innovation component was in evidence during their economic ascent.

The micro-economic rationale for public innovation policy is two-fold: first, government may be better able to take risks and channel funding into riskier but promising technologies; second, direct, state-led investment would allow governments to appropriate more of the returns to innovation, rather than shouldering the risks but letting the returns be reaped by the private sector (Mazzucato, 2015 and 2018).

Figure 5 – Publishing and patenting academic international collaboration

Share of scientific publications with international team *Share of academic patents with international inventors*



Source: Clarivate and WIPO Statistics database. Notes: scientific publications included in SCIE. International teams based on affiliation of authors. International inventors based on country of residence.

However, many national industrial policy frameworks (excepting the relatively unsuccessful "growth pole" strategies of the 1950s and 1960s), largely disregard geography. This creates the risk that public entrepreneurship will follow the geographical patterns of the private sector and largely benefit those regions with strong institutions and favorable conditions. Indeed, virtually all of the countries with highly successful national innovation strategies have high levels of sub-national agglomeration of innovation, wages and incomes, and levels of inter-regional inequality that are as high, if not higher, than those countries where such strategies were less in evidence (South Korea, for example; like Latin American growth poles in the 1950s, which did little to counter internal interregional inequality). In other words, deliberate innovation or industrial policy frameworks have only rarely been able to both raise the national level of innovation and distribute it relatively evenly within the national territory. We discuss geographical polarization and the equity-efficiency issues it raises in subsequent sections of this paper.

The role of public sector strategies should not be limited only to deliberate industrial policies or "state as entrepreneur" (e.g. David, Hall, and Toole, 2000). For example, public sector input comes in more indirect forms that may be difficult to pick up using either expenditure or patent data. Public funding can be used to stimulate additional private sector investment as when in the USA, DARPA challenges award prizes only to winners, but stimulate investment by all contestants. Publicly funded R&D may be carried out in partnership or solely by private organizations, so public sector institutions may not be listed as inventors on patents. The kind of R&D funded and carried out by the public sector would be expected to be very different from that carried out by the private sector, e.g. in terms of riskiness, basic vs applied, etc., so any outputs such as patents might not be directly comparable.

An obvious form of public sector policy has to do with the R&D system and in particular the role of universities and public research laboratories and organizations (e.g. Mansfield and Lee, 1996; Salter and Martin, 2001). In developed countries, the example of the

United States of America (U.S) from 1875 to 1975 is exemplary: the federal Land Grant Colleges system extended research universities to many parts of the U.S., and federal funding for universities reinforced the proliferation of private universities in that period as well. The California system is perhaps the most successful of all, with the public University of California system having 3 of the world's top twenty universities, and 6 of the top 50. The investments required to carry out such strategies are large and must be long-term and appropriately institutionally organized. Analogously, in most of the former middle-income economies that are now high-income and highly innovative regions of the world (South Korea, Singapore, Israel), concerted and successful effort was made to build top-ranked research universities (e.g. Hershberg, Nabeshima, and Yusuf, 2007). In China today, it seems likely that the appearance of top world innovation clusters is related to the investments in top world research universities. Public sector laboratories (such as the CNRS labs or the national laboratories in the USA) also seem to figure in the national innovation profile. But all of these policies may have concentrating internal effects, as it is not practical to have equally well-endowed research universities in every locality, an inherent tension between inter-regional equity and excellence that is present in virtually every European country with a public higher education system today. In today's agglomerated innovation environment, moreover, certain public sector institutions (especially universities are strongly reinforced by market forces that make some more attractive to students, faculty and funders than others, reducing the efficiency of public sector policies for spreading innovation around the different regions.

Ultimately, we have some understanding of policies that work in practice to foster innovation and to influence its geography, but this understanding remains partial (more on this in section 4: agglomeration and clustering). This highlights the need for more robust evaluations, carried out by linking innovation outcomes, such as patents, to other datasets, e.g. business accounts, tax data, and public funding (e.g. Aghion, Akcigit, Hyytinen, and Toivanen, 2017; Akcigit, Caicedo, Miguelez, Stancheva, and Sterzi, 2018; Bell, Chetty, Jaravel, Petkova, and Van Reenen, 2018; Crescenzi, De Blasio, and Giua, 2019a). To maximize value for money, policy makers need to understand where the sweet spot lies, beyond which more innovation inputs do not yield more outputs (Charlot, Crescenzi and Musolesi, 2015).

3 The concentration process: Innovation in urban hotspots or specialized niche clusters

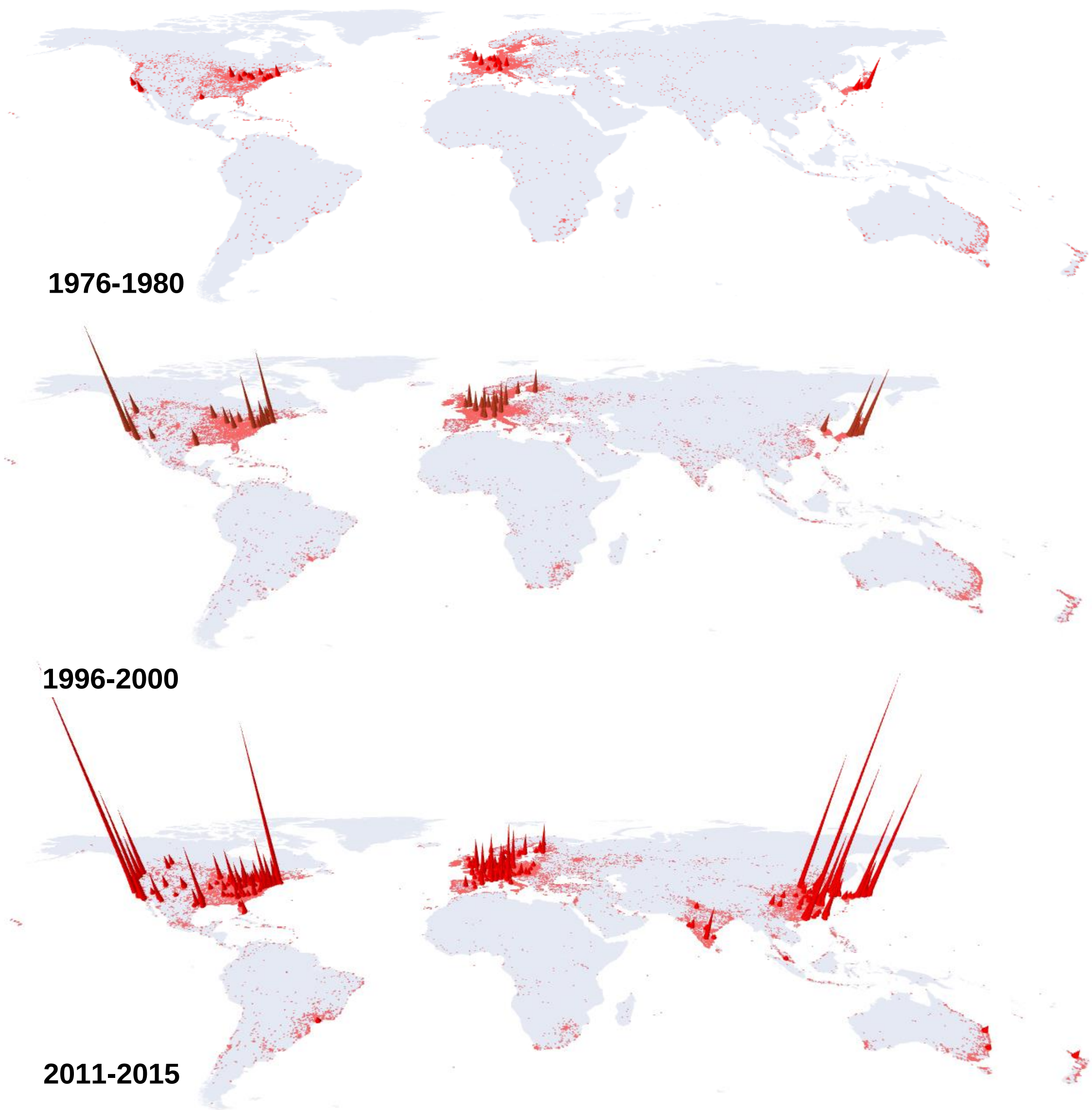
Threaded throughout the discussion of dispersion above, there is considerable reference to regional concentration within a global dispersion process. This is the other major defining characteristic of the contemporary geography of innovation. While innovation activity is growing outside the traditional centers of the US and western Europe, it needs to be stressed that this dispersion is uneven. It is limited to some urban areas in some countries. Not all innovative activity is of the same quality, and some newly innovating countries and regions may be far behind the international technology frontier (Crescenzi et al., 2014; Dunning and Lundan, 2009).

We are currently living through not only a globalization process, but a worldwide urbanization process. This is reflected in the dual geography of our time in general: the global spread of development; the increasing inter-regional intra-national polarization of innovation, wages and incomes, and opportunity. This is a different geography from the period prior to the 1980s, when in most developed countries, inter-regional convergence had been occurring for many decades, with a smoothing of the landscape of wages, skills, opportunity and amenities. As such, the current situation is known as "the great inversion" (Ganong and Shoag, 2015; Moretti, 2012).

Metropolitan areas are the broad beneficiaries of this tendency, though there are still some that are declining, and there has been turbulence in the ranks of highly performing metro areas from the previous (Mechanical-manufacturing) period to this one. In the emerging market economies, too, there is a strong wave of metropolitan economic development associated with their overall industrialization and economic transition.

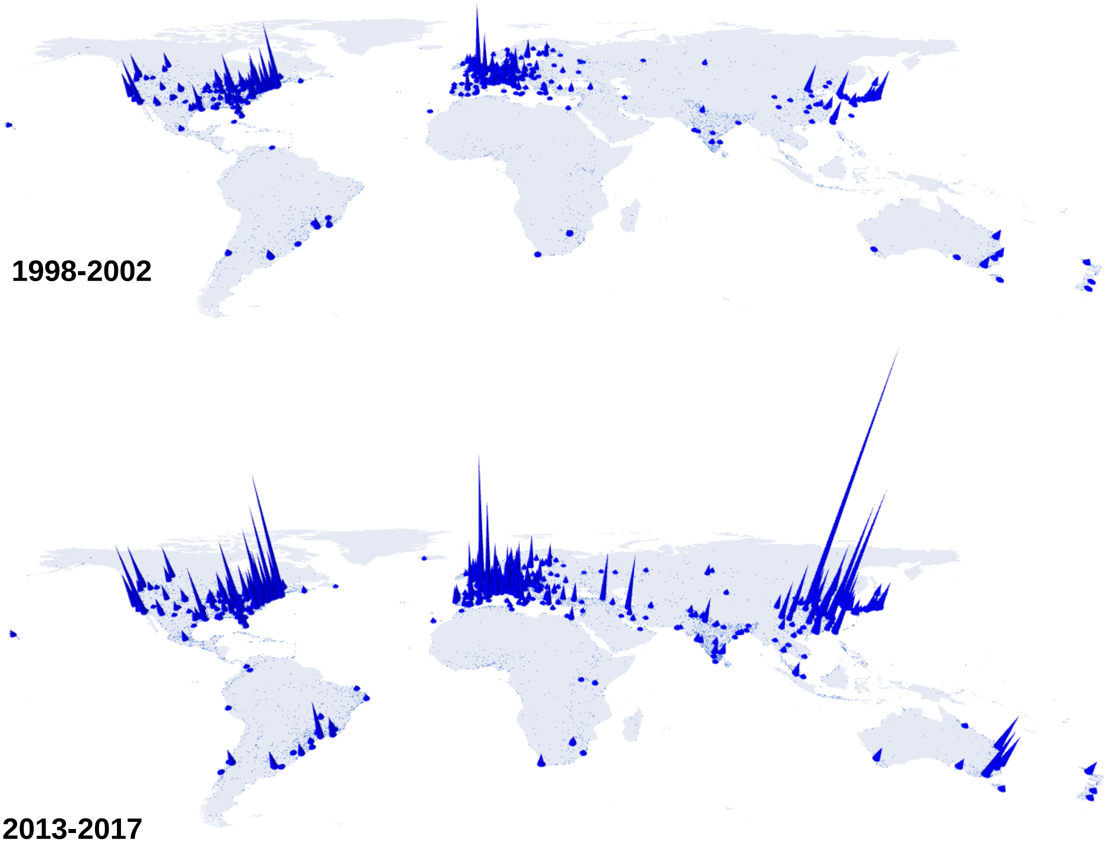
There are many dimensions of this process of geographical concentration, including the spatial concentration of the key trade-able sectors of the Third Industrial Revolution; concentration of the skilled; higher wages to the skilled in cities than elsewhere, and higher returns to the skilled more generally; a higher role for "abstract and cognitive tasks" in these metropolitan areas than in the economy as a whole. All of these are signs that such urban centers are concentrating knowledge-generating and innovation-based work (Kemeny and Storper, 2019).

Figure 6 - Evolution of geographical dispersion of patents, 1975-2015



Source: WIPO Statistics database. Notes: Data aggregated at county, NUTS3 or equivalent administrative unit.

Figure 7 - Evolution of geographical dispersion of scientific publications, 1998-2002 and 2013-2017



Source: WIPO Statistics database. Notes: Data aggregated at county, NUTS3 or equivalent administrative unit.

3.1 Why is there such strong agglomeration of the work of innovation and the organizations that innovate?

Innovation, like any leading edge of the economy, has always had geographical concentrations or hotspots: Manchester was to the First Industrial Revolution what San Francisco is to the Third, in this sense. But for a long period between these two revolutions, within the advanced economies, it appeared that there was an incremental spread of innovation capacities. The strong concentration of innovation since the end of the 20th century thus requires additional consideration. This is all the more the case because innovation, we have seen above, seems to be globally spreading.

We can begin with some of the basics about spatial concentration of innovation. Researchers are more productive in larger agglomerations (Moretti, 2018), and innovation generated in diverse agglomerations tends to be more unconventional (Berkes and Gaetani, 2016; Nathan and Lee, 2013). Agglomeration effects not only spur innovation but increase productivity in general. One estimate puts the effect of doubling employment density on productivity at 5% in Europe (Ciccone, 2002). The effects of R&D spending are highly localized: while doubling R&D spending in a region is estimated to increase innovation outputs in that region by 80-90%, spillover effects in a radius of 300km are estimated at only 2-3% (Bottazzi and Peri, 2003; Crescenzi and Rodríguez-Pose, 2008).

The spatial concentration of innovation activities is mirrored in the concentration of university graduates and science, engineering and technology workers (Davis and Dingel, 2014). In the US, this coincides with a concentration of skilled employment towards larger cities (except the largest metropolitan areas) from small and medium-sized counties, particularly for skilled service jobs (Carlino and Chatterjee, 2002; Desmet and Fafchamps, 2006).

There are some differences between the US and Europe. Europe has a smaller urban size productivity premium than the USA in general, and a bigger role for medium-sized metropolitan areas. City-regions in Europe are not as specialized as their American counterparts in the areas in which they innovate (Crescenzi, Rodríguez-Pose, and Storper, 2007). Thus, compared to the US, and with some additional variation by country, knowledge-intensive services in Europe exhibit relatively low levels of regional concentration. In contrast, high-tech manufacturing activities are highly concentrated (Merino and Rubalcaba, 2012). Germany is still another case: with low levels of urban primacy, Südekum (2008) finds a positive relation between initial skill endowments and subsequent employment growth, but a negative relation with the growth of high-skilled employment, so that even with low levels of urban primacy, the skill distribution across German regions becomes more equal over time.

3.2 Are current innovative agglomerations different from the past?

A key question is whether economic activity clusters along sectoral or functional lines. Firms used to cluster along supply chains. In the First and Second Industrial Revolutions, innovation activity was strongly co-agglomerated with leading production activities, making for large industrial cities, and some that also concentrated R&D and product development.

Over the last century these patterns of co-agglomeration have slowly changed, and location choices have become more determined by shared skill requirements (labor market pooling across different but related innovation sectors), especially in service sectors (Diodato, Neffke, and O'Clery, 2018). In the Third Industrial Revolution, many industries are not heavily capital-intensive in their production activities, and global supply and value chains are far longer and more complex, as mentioned above. As a result, leading innovative urban agglomerations today appear functionally specialized in service sectors generally and in the abstract, cognitive and conceptual tasks of R&D and innovation, with fewer co-located routine production tasks than in past periods (Crescenzi and Iammarino, 2017; Duranton and Puga, 2005). In addition, highly internationalized clusters characterized by strong processes of technological creation and diffusion at the frontier are distinct from domestic firm clusters, where agglomeration economies at play rest more on traditional backward and forward links in production (Alfaro and Chen, 2014).

This implies that clusters are changing in nature in some of the key areas of the Third Industrial Revolution, which in turn militates for updating the definition of what a cluster is and finding meaningful ways to identify today's clusters in the data. Especially as "related diversity" within clusters seems to become more important (Balland, Boschma and Rigby, 2015; O'Sullivan and Strange, 2018), the distinction between an innovative cluster and general agglomeration effects in metropolitan areas become blurred (Iammarino and McCann, 2006). Moreover, the specific organizational content of contemporary innovation agglomerations has certain important differences to the agglomerations of the past. They involve a greater diversity of functional dimensions, which include R&D, universities and education, deal-making, financing, servicing and curating in variable organizational geometries. These "ecosystems" are organized differently from the classical Marshallian agglomerations that consisted of leading companies and their hierarchically organized partners or internal R&D arms.

It should be noted that if innovative agglomerations really are becoming sectorally broader and functionally more specialized in related innovation activities, then the implication from the perspective of spatial development economics is a reinforcement of overall geographical concentration and a tendency toward inter-regional divergence (O'Sullivan and Strange, 2018; Iammarino and McCann, 2018). One of the key issues that theory and research has not resolved about the overall geography of innovation today is its spatial "granularity," meaning the extent to which these related diversity agglomerations can be spread across the landscape (into a larger number of narrower niche agglomerations) or whether they inevitably tend toward metropolitan super-clusters and greater inter-regional inequality.

Before continuing, note that the landscape still contains some more traditional types of clusters in capital-intensive sectors such as mining, mechanical engineering, petroleum, shipbuilding, and aerospace. These might still be generating agglomerations that combine core engineering-production tasks with core innovation tasks, leading their agglomerations to have a different nature from those in IT, life sciences, finance, and entertainment. These differences of co-agglomeration require great attention when measuring the geography of innovation.

Aside from these traditional sectors, the type of innovation clustering at hand generates a persistent problem with terminology about "diversity" and "specialization." This is an important point about how theory is used to interpret empirical results. In the classical terminology, we distinguish between a sectorally-specialized (vertical supply chain) agglomeration (Marshall externalities) and a diversified, multi-sectoral (horizontal) agglomeration (Jacobs externalities). Finally, there are "Romer" externalities having to do with learning, where precisely the question is whether learning is facilitated by specialization or diversity, organized hierarchy or informal interaction.

In this light, many of the top innovation clusters discussed here are not well described by the traditional division between specialization and diversity; hence, terms such as "related diversity" and "related variety" have been suggested, in an attempt to capture clustering of innovation functions around a group of related technologies that may involve many different output sectors but that are linked through complementarities in the use of certain basic innovations, or in complementary ways to innovate into related areas or related varieties of outputs. It is important to understand that, from the standpoint of spatial economics and the "returns to agglomeration," these clusters would be considered "specialized," but that this is not – "on the ground" – referring to the same thing as meant by much of the classical Marshallian or even MAR literature. This leads to confusion in much of the literature about what is actually being measured.

3.3 The geographical open-ness of leading innovation clusters today

Long-distance exchanges of knowledge are not a new feature of the economic system. In the First and Second industrial revolutions, knowledge and hardware travelled, international imitation and rivalry were active parts of the landscape, and there were always networks of people who helped such knowledge exchange along. In the past, however, such exchanges often involved the display and then possible imitation of what was created in a rivalrous agglomeration (as in the Crystal Palace Exhibition in 1871, when the Americans displayed the American System of interchangeable parts to Europeans). Contemporary knowledge clusters have long-distance ties, which have become more organized and extensive over time, and which often involve the co-development of technologies across agglomerations, both within firms and between competing firms.

Thus, knowledge-generating agglomerations today are not self-contained local systems, but rather consist of key nodes in the dispersed GINs that we discussed previously. Indeed, highly productive localized innovation systems are also those that are most tied into long distance relationships of various sorts. New knowledge may be brought into the region through the establishment of extra-local linkages (e.g. Bathelt, Malmberg, and Maskell, 2004; Boschma, 2005; Frenken, Van Oort, and Verburg, 2007). Innovators rely on collaborations both inside and outside the organizations and the regions where they work. There is evidence that geographical proximity is not the only source of knowledge spillovers and recombination today.

This has been operationalized in the notion that there are other, metaphorical forms of "proximity" between the agents involved in innovation (Boschma, 2005). Organizational proximity refers to the organized interactions and possibly lower transaction costs within firms (especially MNEs), research organizations or organized networks, or states. The idea is that these organized structures can facilitate deep interaction without co-location. Institutional proximity refers to actors that operate within unified institutional rules or routines (sometimes including intra-organizational, but not always). This would facilitate interaction within national systems or aligned international rules, and through professional networks facilitated by institutional similarity. Finally, drawing on the classical sociological concept of "ties" between persons, innovators with social proximity – ranging from inter-personal to being part of the same culture or group – are likely to have lower interaction costs, easier verification and higher trust – than those that are socially distant.

Organizational, institutional and social proximity should not be seen as substitutes for geographical proximity. On the whole, social and other proximities probably work in conjunction with geographical proximity (Crescenzi, Filippetti, and Iammarino, 2017; Crescenzi, Nathan and Rodríguez-Pose, 2016a; D'Este, Iammarino, and Guy, 2013). It is probable that geographical co-location is both a cause and an outcome of these other proximities, but we have little way of precisely measuring the sequences by which such different mechanisms come about. This chicken-and-egg nature of different kinds of ties within successful innovation systems is a challenge for using this evidence to generate policies designed to foster different kinds of proximity as potential alternatives to or stimuli to one another.

A key agent in all of these long-distance interactions is, of course, the MNE. As we pointed out in our discussion of dispersion and GINs, MNEs are the most important type of organization and network node in the international spillover of new knowledge. As such, they are inevitably interacting with and having important effects on innovation clusters. MNEs contribute to regional structural change: on the one hand, they may fit into regional profiles of specialization, thus reinforcing the process of local technological concentration; on the other hand, depending upon the initial pattern of regional specialization, MNEs may spur the diversification of the regional profile towards areas of interrelated technological competence. As an example mentioned above, ICT caused a great increase of R&D in some closely related electrical/electronic technologies: such interrelatedness may therefore have pushed the broadening of technological specialization in those metropolitan cores which show greater expertise in information and communications technology because of more diverse but complementary activities and higher spillover effects (Alcácer, Cantwell, and Piscitello, 2016; Cantwell and Iammarino, 2001; Leamer and Storper; 2001). The interactions between regional knowledge bases and MNE technological strategies have been investigated in terms of knowledge spillovers and externalities, particularly in the European (e.g. Ascani and Gagliardi, 2015; Cantwell and Piscitello, 2005; Cantwell and Santangelo, 1999; Crescenzi et al., 2014;) and the US context (e.g. Alcácer and Chung, 2007; Almeida, 1996).

3.4 A Synthesis: Dispersion and Clustering, Globalization and Persistence

The empirical evidence simultaneously points to the importance of the increasing global nature of innovation, as well as growing agglomeration forces and concentration of innovation in specific – often metropolitan – areas. Rather than being substitutes, these trends are complements, reinforcing each other. If there is any single image that can capture this emerging geography it is that of a globalized hub-to-hub system, rather than a geography of generalized spread and convergence. The world system of innovation links national systems of innovation and global firms through a spiky geography of knowledge creation and a global network of these spikes or hubs, many of which are better connected to one another than they are to their national hinterlands in terms of knowledge creation and diffusion.

Moreover, this global network of hubs is not evenly distributed enough at the present time to generate a world geography of technological convergence. International technology gaps have remained relatively stable (Kemeny, 2011). While emerging economies are progressing, advanced economies are able to maintain their advantages by specializing in the most technologically advanced products, and within product classes in higher quality varieties (Bresnahan and Trajtenberg, 1992; cf. Myrdal, 1957; Perez, 2010).

There are also debates about the extent to which the stunning successes of former middle-income economies such as South Korea and Israel can be imitated in the 21st century. The internal features of these economies – with strong egalitarian starting points, strong cultural cohesion, strong states, and very high educational investments – are simply not present in many other developing areas of the world. Moreover, it can be argued that they used the earliest phase of this period of globalization (the 1970s to 1990s) to grow through export-orientation when there were fewer low-wage competitors in the game. In today's world, any economy, even those with strong internal features, would face a tougher export environment in the critical first stage of accumulating experience and resources with which to invest in climbing the technological ladder. Indeed, some less developed economies today may already be undergoing "premature deindustrialization" before they have even gotten to the middle-income, middle-skills range of the world economy (Rodrik, 2016).

On the other hand, competing explanations emphasize the concept of 'latecomer firms' that, unlike established MNEs from developed countries, exploit their late arrival and tap into advanced technologies, rather than having to replicate entire previous technological trajectories (Mathews, 2002). Such MNEs from emerging economies pursue investment in the advanced world due to the possible benefits that accrue from the acquisition of new technologies and innovative capacities by purchasing R&D centers or buying firms with higher technological expertise, enhanced learning opportunities, lower levels of institutional risk and greater market potential. They also may pursue internationalization strategies in other emerging economies: there may be relative advantages in entering environments with similar economic institutions, hence facing lower "liability of foreignness cost" (Cuervo-Cazurra and Genc, 2008; Wright, Filatotchev, Hoskisson, and Peng, 2005; Zaheer, 1995).

Nonetheless, there is a real possibility that a continued rise of Chinese innovation, in conjunction with the already existing Japanese and Korean innovation systems, could generate – in the near future -- a tripolar meta-geography of innovation at a global scale (Western Europe; North America; Northeast Asia). Contributing to this dynamic, we may be witnessing a once-and-for-all decline of the supremacy of the large MNEs from the advanced North as leading investors in both production and innovation (e.g. Iammarino, 2018). Furthermore, a few emerging economies, particularly in Asia, have developed active internationalization policy frameworks to support their domestic firms in 'going global' (Narula and Nguyen, 2011; UNCTAD, 2018).The most salient recent case is China, whose outward FDI has grown at an accelerating rate since 2000, as a result of the adoption of a strong government intervention – progressively articulated at the subnational level – to encourage domestic enterprises to become global (Davies, 2010; Wei, 2013). It remains to be seen whether China will be able to become an original innovator on a broad spectrum of technologies. It is also questionable whether the success of the Chinese model is a one-off coincidence in history or can serve as an example for other economies to adopt.

4 The origins of innovative agglomerations

One of the toughest questions for geography, economics and development studies is to ascertain why innovative agglomerations arise and flourish where they do. This question takes us from the general factors that lie behind the agglomeration of innovation to the specific geographies of those agglomerations, or vernacularly from the “what” and “how” to the “where” question (Storper, 2018; Storper et al 2013; Chatterji et al, 2013). We can now consider several different approaches to the origins question: mainstream “labor supply theories;” accidents of history; size and lock-in; technological relatedness; and deliberate policy. None of them succeeds entirely with this thorny question. This section is principally about the inter-regional scale within countries rather than the international scale (see the discussion of other influences on the dispersion of innovation in section 2 for the international scale).

4.1 Mainstream supply-side models: skilled workers make innovative agglomerations

Mainstream theories offer a number of ways they attempt to account for the geography of innovation: the education and skills of the workforce; the role of immigration in changing the skills base; the effect of housing costs and cost of living on selecting for the skills base (composition of the workforce). Summarizing, most of the emphasis in the mainstream models is not directly about innovation and concentrates on the latter as an indirect outcome of labor supply or labor sorting dynamics (Glaeser and Maré, 2001). In these models, workers with different skills sort themselves into different regions. Highly-skilled workers cluster together because they want to interact with one another. Regions with highly regulated housing markets will exclude low-skilled workers and drive them to regions with lower-cost housing. It is then observed that regions with growth in the share of college-educated workers, per capita incomes, patents, or some other proxy for innovation, were those that had higher than average concentration of college educated in the past. The causal inference is that innovation-based jobs follow people (labor supply), hence shaping differences in specialization, and selective migration according to skills plays a central role (Glaeser, 2008). Even though innovation per se is backgrounded in this reasoning, there is nonetheless a strong implicit view that it (like all other changes in regional economic specialization) is driven by changes in the geography of labor supply through the location choices of innovators (skilled workers). Notice, however, that there is no direct explanation of the geography of the innovation process itself, with little mention of the core mechanism of agglomeration.

Labor supply clearly influences the development trajectory of innovative agglomerations. The characteristics of the local population that matter for the local innovation system, such as skill endowments, employment rate and demographics, can be summarized as social filters. They have been found to impact regional innovativeness, both in the US and in the EU (Crescenzi et al., 2007). Furthermore, they also drive investment location decisions, showing that businesses are aware of the importance of these local assets (Crescenzi et al., 2014 and 2016b).

There may be other factors that drive the agglomeration of innovative activities in certain places, such as the preferences of highly skilled workers both to live in those places as well as to work in innovation (Davis and Dingel, 2019; Schwartzman, 2017), as well as entrepreneurial strategies and deliberate cluster policies (Feldman, 2014; Feldman, Francis, and Bercovitz, 2005; see below). Working in innovation occupations both offers high wages today as well as a career trajectory and life-long learning opportunities that secure future employment opportunities where many traditional white-collar occupations become threatened by automation. Equally important may be the presence of anchor firms or historical accidents of breakthrough innovation in starting an ecosystem that then organically grows as both skilled labor and related activities co-locate.

And yet these factors fail to resolve the “origins” issue, in two ways. First, we can observe that at some points in time, skilled workers spread out geographically; this was the case from 1940 to 1980 in the developed countries, in the maturing phase of the Second Industrial Revolution (Kemeny and Storper, 2019) Hence, any viable theory has to explain why the behavior of the skilled subsequently changed in favor of geographical concentration and referring to a spontaneous change in preferences for interaction is not an explanation at all. Second, skilled workers are not all alike. A finance worker will be attracted to different locations than an IT engineer, and these locations and jobs are not substitutable for one another. This implies that the geography of demand for innovative workers should be seen from the demand side, through understanding why innovative firms and systems arise and agglomerate where they do.

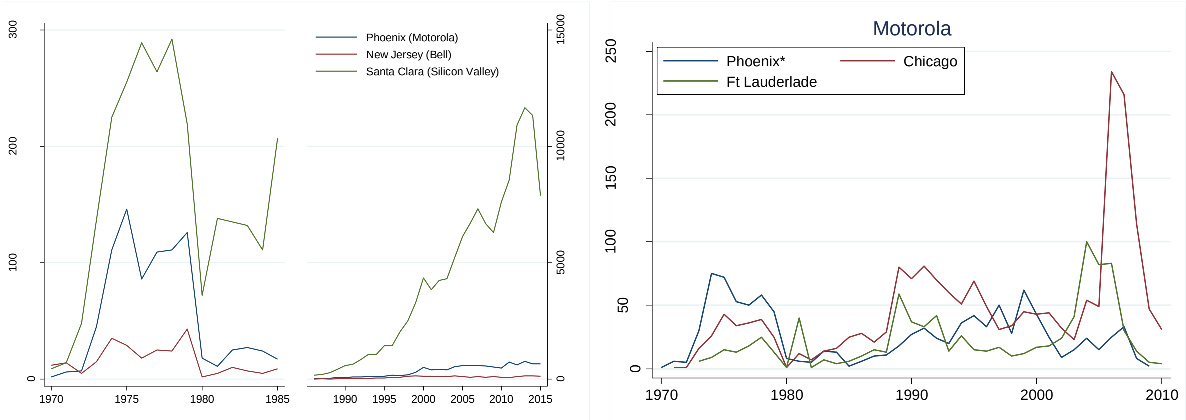
4.2 Innovation Hotspots as a Lottery: Accidents and Shocks

Another possibility is that the geography of innovative agglomerations – especially those that are first movers in the key technologies of each industrial revolution -- is due to random shocks. Key versions of the accident or lottery theory center on either unusual individuals or anchor firms. Thus, in some accounts, Silicon Valley is where it is because William Shockley – the inventor of the silicon-based semiconductor – decided to relocate from New Jersey to be near his aging mother in Menlo Park, California. Another anecdote concerning Shockley is that after he attracted the best associates to his first-mover firm, his difficult management style and abrasive personality caused them all to quit on the same day (known as “Shockley’s massacre”), thus launching the Silicon Valley process of development through spin-off. Many other such great person stories can be found in the annals of innovation.

But doubts can be cast on the randomness of such “great inventor presence” stories. For example, there are so many famous associated with Silicon Valley – from Shockley and Terman to Hewlett and Packard and Jobs and Gates and Brin and Page and Thiel -- that it seems unlikely that all could be there due to coincidence. Moreover, Saxenian (1994) powerfully argued that mere presence of early innovators is not enough. Plenty of the early great IT innovators were located in Boston, but they did not survive. Mark Zuckerberg left Boston for Silicon Valley because Boston was not the right place to transform a breakthrough invention into a fully-fledged innovation, just as had happened to New Jersey decades earlier, when William Shockley left for the Bay Area.

Another idiosyncratic influence on agglomeration might be decisions by key firms at key moments. Motorola located the largest early semiconductor facility in the world in Phoenix in the 1950s, for example, but this did not establish Phoenix as a subsequent center of the IT industry (Scott and Storper, 1987). Motorola made the mistake of believing that it could be a geographically-isolated first-mover in a technologically innovative industry. It turned out that only those firms – such as Fairchild and Hewlett-Packard – who were first-movers but did not isolate themselves from the emerging open source networks of the emerging Silicon Valley were able to keep up with the rapidly-rising technology curve.

Figure 8 – ICT related patenting, 1970-2015



Selected ICT inventor locations *Motorola's main inventor locations*

Source: WIPO Statistics database. Notes: Data aggregated at US county level

4.3 The Size of Agglomerations

The New Economic Geography models a snowball process of how regions progressively draw in supplier firms, human talent and knowledge. Formally, regional agglomerations have economies of scale, driving a wedge between the leading region's productivity and innovation levels and the other regions that host the industry. Once this happens, the leading industry's position is said to be locked-in (Krugman, 1991; Rosenthal and Strange, 2001; Thisse, 2010). However, the advantages from size may be outcomes of successful innovation processes and therefore might express some kind of subsequent advantage but do not explain origins in the face of major technological changes. Scale in one area does not lead straightforwardly to mastering the next wave of innovation.

4.4 Technological Relatedness and Subsequent Specialization

Another common extension of NEG models to regional economic dynamics is the notion that previous technological endowments have a strong role in shaping subsequent capture or creation of innovation. In the comparison at hand, both regions had close technological antecedents of the IT industry. Most detailed historical analyses of the rise of Silicon Valley demonstrate that it grew from the pre-existing communications equipment sector in the Bay Area, but some interpretations stress the discontinuities with respect to that sector, notably in the arrival of William Shockley and the invention of the first market-friendly semiconductor (Lécuyer, 2006: Storper et al 2015).

And yet, there appear to be many other examples of regions that capture major new sectors with little technological relatedness to their pre-existing activities. Los Angeles was not a major mechanical engineering region in the 1920s and 1930s, when it became the aircraft engineering center of the US and, by the 1940s, the world's biggest aerospace cluster. Los Angeles had no previous background in the entertainment industry when the movie studios were established there around 1915. Detroit had fewer antecedents in mechanical equipment than Illinois in the 1890s, but rapidly became the center of US car technology and manufacture. In these, and many other examples, there were technological "windows of locational opportunity." These ruptures in technological relatedness largely obviate the advantages of pre-existing agglomeration economies and create a relatively flat playing field for a short time in the early days of a technology's existence (Scott and Storper, 1987).

Additional arguments about antecedents can now be considered. One such argument is that more diversified economies have a greater probability of successful transitions than narrowly specialized ones. This idea, often attributed to Jane Jacobs (1961), holds that evolution is a probabilistic process, so that having more irons in the fire will enable more likely recombination into future success. Theoretical models of "nursery cities" draw on it (Duranton and Puga, 2001).

The literature also abounds with stories of how narrowly-specialized economies are locked-into their technologies and do not transition after negative demand shocks or technology shifts. Thus, Detroit is held up as a case of over specialization. And yet there are highly-specialized center of mechanical engineering and automotive technology that have mastered subsequent waves of technology, such as Stuttgart. Boston was once narrowly-specialized in mill-based industries, as was Seattle in forest products and mechanical engineering, but both are high-tech centers today.

Benjamin Chinitz (1961) made a more subtle argument about the qualities of antecedents. He argued that dominant industries tend to monopolize talent, factor supplies and attention, potentially crowding out other activities, and hence they can channel the evolution of regional economies down distinctive pathways. New York's antecedents were said by him to be more favorable than those of Pittsburgh. Evolutionary economic geographers give this notion a specific contour, holding that antecedent technologies matter, such that the capacity for regional economic evolution is governed by possibilities for moving into cognate technologies, which they dub "related variety" (Frenken et al., 2007).

A somewhat different version of the evolution argument combines technological and organizational antecedents. Saxenian's (1994) seminal comparison of Route 128 and Silicon Valley can be interpreted as showing that the types of entrepreneurship, production organization, and system coordination that existing firms and actors know in a region will shape what it becomes and what kinds of new activities it can generate and capture. And yet Seattle was dominated by the assembly lines of Boeing and by large-scale natural resource companies, but now is considered the home to some of the most innovative companies in the new economy, who are revolutionizing many organizational practices.

4.5 Do deliberate innovation policies generate innovation agglomerations?

There is little systematic large-scale evidence of the success of policies trying to create new local clusters. The last several decades are littered with failed "technopolis" or "the next Silicon Valley" policy initiatives (Chatterji et. al, 2013). Government subsidies might actually attract the "wrong" kind of firms that have low productivity and depend on subsidy for survival, or who are not in fact open to creating networks among local firms, for fear of leaking IP (Zhu, He, and Xia, 2018). Because of the path dependency of industry growth and cluster creation, it is questionable how much policy can achieve. Like in nature, firms form *ecosystems* that are not easily transplantable or reproducible, as they develop embedded in territorially specific institutional settings and social fabrics (Ascani, Crescenzi and Iammarino, 2012).

But the above does not mean that all policy has failed in influencing cluster formation. In the USA, a notable success story – perhaps not equivalent to Boston or Silicon Valley, but still successful – is Research Triangle Park in North Carolina (Feldman, 2014).

There are a few selective examples of successful government intervention to generate clusters in technologically-emerging economies. For example, in 2008, the municipal government of Chongqing, China, successfully helped to transplant several smaller coastal notebook computer manufacturing clusters into the city. Businesses were incentivized by investments in infrastructure, labor market organization, and other business-friendly policies.

However, this is a cluster that was moved, rather than growing organically. The government in Chongqing benefitted from extensive powers and good connections to the central government to facilitate its goals. This also facilitated the implementation of policies to attract inward FDI, such as reduced taxes and social costs and public investment in infrastructure. Other initiatives in China took different approaches depending on capabilities and powers of the local administration. The IT cluster in Bangalore, India, is a similar example that was however incubated by investment in the India's space program in the area, and then grew organically, supported by investment in infrastructure and human capital (Gao, Dunford, Norcliffe, and Liu, 2018). All of these clusters started as manufacturing hubs and became innovative to varying degrees with the maturing phase, but also involved significant involvement from multinationals (Athreye, 2005). Policies to increase innovativeness may be unsuccessful if the support is only indirect, aimed at increasing demand for new technologies by supporting downstream industries. Policies to increase demand for innovations frequently result in increased transfers of technologies into the economy, but do not lead to more domestic innovation. To achieve that goal, direct support of innovation activity, such as R&D subsidies or tax credits, may be more successful (Fabrizio, Poczter, and Zelner, 2017).

Beyond the mechanisms driving clustering and economic performance, there are several factors that determine the location of innovation hotspots today. Anchor institutions such as universities and MNEs may be important factors. As for the former, the presence of a university in itself is not enough to generate innovation in a region (Arora, Cohen, and Cunningham, 2018; Faggian and McCann, 2009). In addition, although industry-university innovation partnerships are more likely to occur among geographically proximate partners with previous joint experiences, geographical clustering of technologically complementary firms makes the spatial proximity of industry and university partners far less important, or even irrelevant in the case of the most densely and related firms' clusters (D'Este et al., 2013).

4.6 The change process: origins in relation to path-dependent evolutions

Ultimately, the origins question cannot be cleanly separated from the past of a region, nor from its subsequent evolutionary future. There is a two-sided process of stability and change in observing the map of innovation.

On the one hand, as argued above, certain kinds of major technological changes may generate windows of locational opportunity that can give rise to major new first mover agglomerations, or to significant turbulence in the ranks of already innovative regions.

But on the other hand, by definition there can only be so many first-mover or "greenfield" innovation centers. Most established innovation systems are highly path dependent, i.e. dependent on historical industry concentrations and social linkages (Moulaert and Sekia, 2003). The interaction of the development of new technologies and the spatial organization of economic activity are highly complex and dependent on the social and institutional environment (Freeman, 1991). Balland, Boschma, Rigby, and Roesler (forthcoming) use patent data to show the path dependency of technological change in US metropolitan areas. They establish the technological relatedness between different technology fields based on patent citations, and then map the specialization of MSAs over time. They find that MSAs that develop their specialization within related fields enjoy stronger economic growth as they are able to build on existing knowledge. They call this "complexity" and "related variety."

Deepening this gradualist perspective, it seems that many regional profiles of specialization are rooted in local environments and the sectoral patterns of technological activity gradually changes as new industries develop and new technological linkages are forged between sectors. However, specialization tends to move along a cumulative path in which the creation of new technological competencies depends on the pattern of advantages previously established. In other words, the broadening of specialization into complementary areas (what some are now calling "related variety,") is one of the possible forms of incremental change in the composition of regional innovation, whilst in other cases regional profiles may be reinforced and concentrated in their established areas of technological expertise.

Whilst this gradual and path-dependent evolution may be the key strength of many regions, it can also pose a problem when rapid and radical technological opportunities wash over the economy as a whole. How can established agglomerations, even those with many existing strengths, capture such changes if they take technology in a radically new direction? Is there a way to maximize the strengths that emerge from the existing system and yet to do so in a way that enables maximum move into new areas? Must such areas always be "adjacent" (in the sense of technologically closely related), or can they also involve breaking away into new areas? And could emerging places be in a better place – less accumulation, path dependency, risks of lock-in – to jump on new technological bandwagons? Can all places (including less developed structurally disadvantaged regions) follow the same type of technological trajectory or can 'low-tech' activities offer valuable niches for (product and process) innovation? These are cutting edge questions which existing theory and evidence do not answer in a definitive way at the present time.

4.7 The need for a better integrative micro-model of agglomeration and dispersion of innovation

As can be seen from the discussion of dispersion and concentration, at the two scales of international and inter-regional, and involving various kinds of proximities, networks, actors (MNEs, individuals, states, smaller firms, universities), and many different sectors and their interrelationships and spillovers, we try to analyze very complex processes with patches of empirical evidence. But it is difficult to bring it together in any unified way. This may be inevitable as a consequence of the messy reality of innovation. But it would nonetheless be useful to have good theoretical frameworks to integrate interpretation of the empirics and orient future data collection and analysis.

Such frameworks would give us better analytics of the spatial divisibility of innovation systems. They would enable us to separate out what goes together and what splits apart in terms of the fundamental "units" of innovation in the economy and whether there are any relatively parsimonious principles of divisibility versus agglomeration. A second dimension of such theory would enable us to explain better the process of development of places (regions, countries) over time. To what extent is innovation an outcome of gradualist and incremental processes of "related diversification", building on what the region has into greater economic complexity? Alternatively, when do existing patterns of advantage get broken by the advent of new technologies that replace old ones, whether in outputs or in techniques? Who captures the new technologies and generates centers if and when there are breaking points in the process that obviate or dramatically reduce the value of existing skills and capacities?

5 Innovation efficiency, in relation to geographical inequalities and inter-personal inequalities

In this final section, we assess some of the distributional consequences of the geography of innovation in the 21st century, as well as how it may affect the overall contributions of innovation to economic performance and development. The geography of innovation has many and sundry links to questions of efficiency and equity. At the outset, we signal that there are more questions than answers about these issue, but that they are sufficiently important to raise even with partial knowledge because of their significance for economy and society.

As noted, there is considerable evidence of a positive relationship between innovation productivity and its spatial concentration and specialization. Nonetheless, even though it maybe optimal for innovating firms to co-locate in ever larger agglomerations, this may not be efficient from an aggregate point of view. A highly concentrated innovation sector may increase spatial development inequalities within and across countries. Jobs in innovation-related activities tend to pay higher wages than in other functions and the spatial concentration of these jobs is contributing to growing spatial inequality overall. Rapid growth in a concentrated geographic area and within a particular sector may have further effects on the local economy. While high-skilled jobs create a larger number of low-skilled jobs (Moretti, 2012), inflows of high-earners combined with inelastic housing supply often result in growing inequality and falling disposable income for low earning households. Ultimately, this leads to increased sorting by skill groups into innovative, high-earning areas and non-innovative, low-earnings areas, excluding the low-skilled from the opportunities and amenities of living and working in an innovative environment (Diamond, 2016). Is this compensated to some extent by social mobility and opportunity for the less skilled, as well as long-term experience for the benefits that compensate their high costs of living when they are young?

These patterns are clearly evident in the so-called 'global cities' displaying particular combinations of economic and social openness allied with key hard and soft infrastructures and monopolization of financial and political powers: they have acted as key nodes in worldwide- production, technology and trade networks (e.g. Iammarino, Rodríguez-Pose and Sassen, 2001 and 2009; Taylor, 2004). They are the primary homes and hosts of major knowledge-based MNEs and the true beneficiaries of globalization, being centres of political influence, corporate decision-making and control, knowledge generation and exchange, skills and jobs (e.g. McCann and Acs, 2011; Yeung, 2009). But their prosperity is accompanied by high levels of income inequality, spatial segregation within them, and a growing split with the so-called "Left Behind Regions" (Rodriguez-Pose, 2018), leading some to speak of a new "urban crisis" (Florida, 2017).

5.1 The distributional effects of innovation: using trade theory as analogy

The forces that generate the contemporary geography of innovation that we have described above are extremely complex and heterogeneous. It is difficult, therefore, to comprehensively capture the ongoing distributional effects of the emerging geography of innovation. But using some conceptual categories from trade theory and New Economic Geography, we may suggest the broad outlines of the questions that should guide further research and reflection both national and global scales.

Models in the Helpman-Krugman tradition (Grossman and Helpman, 1991; Krugman, Fujita and Venables, 1999) predict the specialisation patterns into *core* and *periphery* regions. To some extent, this model can be applied to the innovation sector as well, with the core specialising in innovation and the peripheral areas specialising in production and distribution. The classical models assume free knowledge flows. Crucially, the agglomeration of innovative activities is testament to the fact that knowledge does not flow freely, so trade models underestimate the geographical concentration of innovation production and the associated rents and incomes.

An alternative way to model the forces behind the agglomeration of innovation is by analogy to intra-industry trade. In this view, specialisation is a result of geographically concentrated knowledge, with exchanges among specialised clusters through GINs. This implies that clusters are relatively welfare enhancing in the aggregate (raising world returns to innovation) because of the positive effects of innovative specialisation and a reduced number of clusters or countries investing in the same areas of innovation, often making such efforts repetitive and redundant.

But there can be other effects. Concentrating innovation in a smaller number of bigger and more specialized regions at both national and international scales can have many different distributional effects. While raising the overall economy-wide rate of innovation, if innovation activity spatially concentrates, then other regions may be deprived of the possibility of becoming innovative in the future. On the other side of this, if the more innovative output of the economy as a whole generates innovations that can subsequently be spatially spread through absorption, then one uneven process may feed a spread of subsequent benefits.

If the higher economy-wide rate of innovation creates widespread income benefits (through wages and prices), then its spatial concentration may be compensated in these ways. But if the labour market effects of spatially concentrated innovation are also skill-biased and geographically concentrated, then a set of inequality-increasing effects would reinforce one another.

We are far from having adequate ways to measure all of these effects and interactions at the present time, but it is worthwhile to keep in mind the big picture of potential social, economic and spatial distributional effects of the complex plumbing of the world's innovation systems.

5.2 Is innovation for winners only? Are current innovation agglomerations "too big?"

One particularly important distributional effect of the geography of innovation today calls for further attention here. An extensive literature points to two disquieting tendencies in recent years. One is an overall productivity growth slowdown observed in many countries (Gordon, 2014 and 2018).[2] The second is declining R&D productivity (Bloom, Jones, van Reenen and Webb, 2018). If R&D productivity is declining, then all else equal, increasing agglomeration might produce economies of scale to compensate for the increasing unit cost of R&D outputs (Bloom et al, 2017). However, as clusters become more concentrated both geographically as well as being dominated by fewer, larger players, continuing high returns to innovation may also be a sign of market dominance and monopoly rents (Feldman, Guy and Iammarino, 2019).

Whether the current size distribution and population of agglomerations reflect true productivity gains or oligopoly rents is another important open question for research. If the latter is the case, then the counterfactual is greater aggregate innovation from more spread out innovation. In this light, we do not yet know whether the current state of high clustering of innovation is simply because the Third Industrial Revolution (and possibly its morphing into a 4th) has not yet matured enough to give rise to a spreading out process, as occurred with the manufacturing-based Second Industrial Revolution in many countries in the middle of the 20th century (Kemeny and Storper, 2019). The possibility of 'extended learning curves' implies that, for new investments in knowledge and technologies to fully deploy their benefits, it is necessary to develop complementary and related innovations – technical, organizational, but particularly social and institutional – which might require exceptionally long evolutionary processes of learning and adjustment (see, among others, David and Olsen, 1992; Freeman and Soete, 1994; Gordon, 2000; Pérez, 2010 Wilson, 1995)

[2] Against this interpretation, some others argue that traditional measures of both innovation and economic growth fail to capture growth in the digital age, where innovators may not seek IP protection and rather keep innovations as trade secrets. Equally, output growth, particularly real output growth is difficult to capture as many digital products are "free" to consumers and quality increases from market-disrupting products are difficult to capture. Ultimately, a lot of innovation for the next Industrial Revolution might still be building up.

On the contrary, if -- as we have argued above -- today's agglomerations are fundamentally different from those in the past, then we may never get the spreading out effects that were witnessed in the past, and this would in part be due to the fundamental nature of today's functionally specialized agglomerations, as well as political economy effects such as oligopoly and rent-earning. Along these lines, some historians of technology argue that for much of the 19th and 20th centuries, innovation capacities were more evenly distributed than they are today. Meisenzahl and Mokyr (2012), for example, argue that in the First Industrial Revolution, innovation came from many sources through a process of incremental "tweaking" of major technologies. Phelps (2013) claims that "mass flourishing" was generated through socially and spatially distributed "grassroots innovation" capacities in the Second Industrial Revolution.

This in turn raises the question of whether there is a potential variety of equally efficient geographical configurations of innovation. Research comparing Europe to the US suggests that the model of large agglomerations of the US has been more successful in the 3rd Industrial Revolution than European-style spread (Crescenzi et al., 2007 and 2012; Feldman and Storper, 2018). It is unclear whether the US model will still be successful in the 4th Industrial Revolution or would be desirable from a political perspective. Depending on a country's position on the overall innovation frontier, there may also be different efficient geographies of innovation.

The lesson is that we need to think of innovation not only as the essential motor of the economy, but also that once we introduce its geographies and the causes behind such geographies, it can be seen to be a societally-embedded change process with complex collateral effects. The geography of innovation is ultimately not just about spatial distributions of innovation, but engages debates about market structure, efficiency, rent-seeking, competition, and income distribution within and between countries.

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