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The Geography of Innovation and Development:

global spread and local hotspots

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The Geography of Innovation and Development: Global Spread and Local Hotspots

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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 and illustrates these trends using patent data. 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.

JEL Codes: O33, R12
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1. Introduction: The geography of innovation in the Third Industrial Revolution

Since the time of the first industrial revolution in the early 19th century, innovation has not only been a motor of economic growth; it has also strongly shaped unequal geographical patterns of development and distributions of income. The contemporary geography of the wave of innovation known as the Third Industrial Revolution involves a complex rescaling compared to the past, with innovation becoming at the same time both more global and intensely localized. This has led to new forms of agglomeration, with strong impacts on the distribution of income. In this paper, we synthesize and integrate the two literatures on the global spread of innovation on the one hand and the local innovation activity on the other. While the former emphasizes the global rate of technological progress and global income convergence, the latter focuses on clusters of innovation activity and the local economic development effects.

We demonstrate that global spread of technology development is increasingly associated with stronger metropolitan-scale concentration. These trends can be seen as complements rather than substitutes for one another. If there are images that can capture this emerging geography it is that of a globalized hub-to-hub (or hotspot to hotspot) system, or concentrated dispersion. The world system of innovation links national and regional 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.

The world's wealthy countries experienced inter-regional income convergence from about 1940 to 1980, but since then it has largely come to a halt or been reversed, and high incomes are now increasingly metropolitan, in both the developed and emerging economies. Skilled workers now flow more to metropolitan areas than in the 20th century, although selectively, with some older metropolitan areas never having recovered fully from deindustrialization. Most of the highest income 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).

2. Data

To document the shifting global geography of innovation, we use patent records from the OECD REPAT database1. The dataset includes individual records of patents filed with the World Intellectual Property Organization (WIPO) under the Patent Cooperation Treaty (PCT), as well as patents filed with the European Patent Office (EPO). These are matched to TL3 regions by inventor and applicant. The database covers 1964 to 2018, although there are only few patents before 1978 and few after 2016. All figures below are cut off before 1980 and after 2016. Detailed technology classes are provided (e.g. "G06K 19/07739"). Overall, there are 6.8 million individual patents in the database. Applicants are from 230 countries and 5431 TL3 regions, including some cross-border regions that are not attributed to a single country.

The figures below are based on the inventor location and include PCT filings only. Patents that have multiple inventors from different regions are assigned based on the number of inventors in each region, e.g. if there are two inventors from two regions, each region is assigned 1/2 patent. If there are three inventors with two in region A and another one in region B, region A is assigned 2/3 of a patent, and region B is assigned 1/3 of a patent. While Hong Kong and China are treated as Chinese regions in the OECD classification, Hong Kong and Taiwan are analysed separately from Mainland China below, because they operate as distinctive economic territories.

Patents can be filed in multiple technology classes. In fact, this is the case for most patents. Therefore, when analysing filings by class below, this is based on the number of patents that were filed in a particular class, but assignments are not mutually exclusive. When looking at shares of patents filed in different classes, the totals add up to more than 100% because of this overlap. Where a figure presents the number of patents by class, this is the absolute number of classes filed, and patents are not counted fractionally (i.e. a patent would not be counted as ½ if it was also filed in a second class.

As patent classes are very detailed, we need a classification that is economically meaningful. The analysis below is based on eight broad technology classes. Additionally, the OECD has developed a taxonomy of Information and Communications Technologies (ICT) based on the International Patent Classification (Inaba and Squicciarini, 2017). This classification, known as the "J-tag", as it was developed in collaboration with the Japanese Patent Office, groups ICT-related patents into 13 technology areas and 25 sub-areas. In the analysis below, we rely only on total ICT filings, and look at the detailed classes in the last section. All definitions can be found in figure A1 in the appendix.

[1] Available at: http://www.oecd.org/sti/intellectual-property-statistics-and-analysis.htm

3. The Geography of Technology Production: Dispersion and Concentration Forces

There are many outstanding debates about the precise origins of the first industrial revolution in the 17th and 18th century, 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. Increasingly systematic and cumulative development of new theoretical knowledge allowed for systematic application, yielding a productivity revolution (Acemoglu, Johnson, and Robinson, 2005; Mokyr, 2005).

These twin revolutions – scientific and industrial or technological – introduced a distinctive geographical development hierarchy to the world economy, beginning in the late 18th century, known as the Great Divergence (Pomeranz, 2000). It enabled a selected set of regions and cities in Europe to rise to the top of the global hierarchy of incomes and development (Crafts and Venables, 2003). Since then, each successive major industrial revolution has had its own distinctive geography. 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. The benefits spread widely through the territories of innovative countries, down their urban hierarchies, generating a tendency to inter-regional income convergence in the middle decades of the twentieth century (Kemeny and Storper, 2020; Rosés and Wolf, 2019).

More recently, a Third Industrial Revolution began around 1980, with a Fourth possibly here or on its way (Baldwin, 2016). The Third IR broadly involves information and communication technologies, life science and biological technologies, financial engineering, and significant breakthroughs in transport and logistics. The geography of economic development in this period has undergone some significant changes. 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, except for 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). This is because not all innovative activity is of the same quality, and some of the new middle-income countries and regions remain far behind the international technology frontier (Crescenzi, Pietrobelli, and Rabellotti, 2014; Dunning and Lundan, 2009). As we will see below, only South Korea and China (with Japan already firmly established in the 1980s) emerge as significant contributors to global innovation production.

Despite the global spread of development, many countries witness increasing inter-regional polarization of incomes and opportunity, manifested in the rise of superstar cities and left-behind regions, geographical concentration of skilled workers, and the rise in urban wage premiums for those workers (Giannone, 2017; Autor, 2019). This is a different geography of income distribution from the period prior to the 1980s, when in most developed countries, inter-regional convergence had been occurring since the 1940s, 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, 2017; Moretti, 2012; Kemeny and Storper, 2020; Florida, 2017; Davis and Dingel, 2019). The concentration of technology production in sub-national metropolitan hotspots mirrors the geography of per capita income and the increasing concentration of the skilled in hotspots.

3.1. Dispersion process

In the First and Second industrial revolutions, knowledge and hardware circulated extensively across national borders. The difference today is that knowledge does not just diffuse but is created in collaboration across space. 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. 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). The additive nature of innovation implies that this new knowledge then feeds back into the innovation process.

However, this global network of hubs is not evenly distributed enough at the present time to generate a world geography of international technological convergence. International technology gaps have remained relatively stable (Kemeny, 2011). While emerging economies are progressing, advanced economies have in general been able to maintain their position at the top of the world technology ladder by specializing in the most technologically advanced products, and within product classes in high quality varieties (Bresnahan and Trajtenberg, 1995; Myrdal, 1957; Perez, 2010). As we will see below, only South Korea and China have advanced their innovative capacity to the technology frontier in recent years.

Among the drivers of the dispersion of innovation activity are multinational enterprises (MNEs). 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 UK, this share was already relatively high during the 1960s. In contrast, internationalization of Japanese MNEs progressed slowly during the 1960s and 70s, and it is still comparatively low. From the mid-20th century until 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).

The global spread of innovation is not only due to the advent of global networks and the flows of knowledge through them, and MNEs based in developed economies, but also to national innovation strategies and policies that succeeded in building world-class innovation systems in a set of formerly middle-income economies. These include South Korea, Taiwan, Singapore, and Israel, and – more recently – China and India (Amsden, 2001; Wade, 1990). The concept of the National Innovation System (Freeman, 1987; Lundvall, 1992; Nelson, 1993) refers to the interlocking set of institutions, investments, strategies and practices that stimulate innovation and drive the innovation specializations of countries down particular pathways. Originally applied to the advanced countries, it was subsequently extended to the developing world (e.g. Lundvall, Joseph, Chaminade, and Vang, 2009). The spread of innovation globally seems in part to be due to the spread, however limited, of successful national innovation systems.

In any innovation system, the public sector, academic and other research institutions are key actors alongside private-sector firms, investors and many other kinds of dealmakers and intermediaries. Public R&D spending is declining as a share of total R&D in advanced countries (Filippetti and Archibugi, 2011; Mazzucato, 2015), but this is not the case in emerging economies. In many of the most successful emerging economies today and the now developed former middle-income economies, industrial policy with a strong innovation component was in evidence during their economic ascent and beyond (Archibugi and Filippetti, 2018).

But all of these policies may have concentrating internal effects, as it may be more efficient to target scarce resources than spreading them evenly but thinly. For example, evidence from the UK suggests that public R&D funding disproportionally benefits economically stronger regions (Forth and Jones, 2020). 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.

3.2. Concentration process

While innovative activity is spreading globally, there are strong agglomeration forces at play that result in clustering of innovators and innovative firms and institutions. Researchers are more productive in larger agglomerations (Moretti, 2019). Innovation generated in larger, more diverse agglomerations tends to be more unconventional, in the sense that those patents cite previous patents from an unusual range of technology classes (Berkes and Gaetani, 2020; 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).

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 some larger cities from small and medium-sized counties, particularly for skilled service jobs (Carlino and Chatterjee, 2002; Desmet and Fafchamps, 2006). This picture is complemented by evidence of both international and inter-regional migration of graduates in general and inventors in particular towards innovative regions, reinforcing their lead over lacking regions (Breschi, Lissoni and Tarasconi, 2014; Faggian and McCann, 2009; Iammarino and Marinelli, 2015; United States Congress, 2019).

Localised networks are among the centripetal forces, attracting agents to dense labour markets (Capello and Faggian, 2005; Maskell and Malmberg, 1999). The strength, type, quality and breadth of ties within the network, can be described as different levels of "embeddedness", facilitating diffusion of knowledge and enhancing collective learning in clusters (Giuliani, 2007, p. 140). These effects are of direct benefit to the skilled, who can reap learning and experience premiums by being in the geographical hotspots of where networks are deep and their key nodes are centralized (De la Roca and Puga, 2017). While the city-size premium used to benefit workers across a wide spectrum of occupations, evidence suggests that more recently, only skilled workers benefit, contributing to the rapid growth in geographical differences in the wages of the skilled, and widening wage gaps within cities (Autor, 2019).

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, Rodríguez-Pose, and Storper, 2007). Furthermore, they also drive investment location decisions, showing that businesses are aware of the importance of these local assets (Crescenzi, Pietrobelli, and Rabellotti., 2014 and 2016b).

Geographical proximity is not the only source of knowledge spillovers and recombination today. This notion has been operationalized by means of 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. Institutional proximity refers to actors that operate within unified institutional rules or routines (sometimes including intra-organizational). 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 (Granovetter, 1973; Lissoni, 2001; Uzzi, 1997).

Yet, organizational, institutional and social proximity have not been shown to be 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). Moreover, geographical co-location may be both a cause and an outcome of these other proximities. If various kinds of proximity are needed for successful innovation, the problem is that we know little about the causal sequences by which such different proximities come about. In effect, we know little about whether innovation can be started with a given kind of proximity, or whether some proximities are outcomes of other features of a successful innovation system.

We noted earlier that MNEs are key actors facilitating the growth of the global innovation system. But they also reinforce the key nodes in that system, innovative agglomerations. MNEs tap into regional strengths and might improve them further, thus reinforcing the process of local technological concentration. On the other hand, MNEs may spur the diversification of the regional profile towards areas of interrelated technological competence. For example, the rise of ICT in the 1980s stimulated increases of R&D in some closely related previously existing electricity and electronics technologies. Such interrelatedness may therefore have pushed the broadening of technological specialization in certain metropolitan cores that were specialized in 2nd IR electrical technologies, toward the newer 3rd IR ICT technologies (Alcácer, Cantwell, and Piscitello, 2016; Cantwell and Iammarino, 2001).

These patterns are evident in the superstar cities that are also often key nodes in worldwide production, technology and trade networks (e.g. Iammarino, Rodríguez-Pose and Storper, 2018; 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 centers of political influence, corporate decision-making and control, knowledge generation and exchange, skills and jobs (e.g. McCann and Acs, 2011; Yeung, 2009; Feldman, Guy and Iammarino, 2019). 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” (Rodríguez-Pose, 2018), leading some to speak of a new “urban crisis” (Florida, 2017).

4. The Spread Process: Global Innovation Networks

There is considerable interaction between the geography of trade and the emerging geography of global innovation, with some important differences in resulting patterns. Compared to previous waves of globalization, the current wave, since 1972, has a much higher proportion of intra-industry trade 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. This is true of knowledge as well, where innovation involves the circulation and recombination of ideas across multiple regional and national contexts in complex global innovation networks (GINs).

The integration of East Asian economies into the global innovation landscape is evident in figure 1, starting with Japan in the 1990s. In the early 2000s, patenting activity in South Korea takes off, albeit on a flatter trajectory than Japan's. From the mid-2000s, China enters the picture, with exponential patenting growth from around 2008. Despite the rapid growth in patenting in these countries, North America and Europe continue to hold their dominant position. Note that Germany is plotted on a separate line to the rest of Europe, bringing the total European contribution to a similar level as North America. It remains to be seen whether the East Asian economies will overtake North America and Europe, or whether we are entering a new era of more globally balanced innovation.

What is also clear from figure 1 is that patenting activity in other emerging economies is still lacking far behind the incumbents and new East Asian stars. The figure includes Brazil, India and Russia, but their total annual patenting remains very low. For other countries in the rest of the world, slow but steady growth can be noticed.

[Figure 1 around here]

The rise of the East Asian economies' innovation capacity has to be seen in the broader context of their development trajectory. In developing this capacity at speed and on a significant scale, government action played a key role. However, the public sector influences innovation through much more than deliberate industrial policies (e.g. David, Hall, and Toole, 2000). An obvious form of public sector policy with a distinctive geography is the role of universities and public research laboratories and organizations (Mansfield and Lee, 1996; Salter and Martin, 2001). In most of the former middle-income economies that are now high-income and highly innovative regions of the world (besides Japan and South Korea, also Singapore, Israel, Taiwan, with China on a promising trajectory), concerted and successful effort was made to build top-ranked research universities (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 (National Science Research) labs in France or the national laboratories in the USA) also figure highly in the national innovation profile. These strategies follow examples of developed countries. The United States from 1875 to 1975 is exemplary: the federal Land Grant Colleges system extended research universities to many parts of the United States, 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 (Nervis, 1962).

Growing investments in education and research universities have a secondary effect on the global dispersion of innovation, by creating cohorts of highly trained scientists and engineers that are increasingly globally mobile. 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 diffusion of innovation by becoming a key glue in GINs (Miguélez and Moreno, 2013). Saxenian (1999) explores the interaction of people and investment networks through the mobility of skilled Chinese and Indian entrepreneurs in Silicon Valley. As these skilled entrepreneurs move around, they engage in sharing knowledge, leading to a 'brain circulation'.

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. In this respect, the growing dominance of East Asian economies in physics and electricity patenting classes, as shown in figure 2, can also be seen as a sign of the growing sophistication of their economies. In contrast, 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 mechanical engineering and mining/energy (Krammer, 2009).

[Figure 2 around here]

The relation between the global division of labor and innovation activity becomes clearer when considering the activities of Multinational Enterprises (MNEs). It has long been debated whether multinational enterprises are 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). Reconciling the two positions, 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 (Catellani and Zanfei, 2006 and 2007). However, while the internationalization of R&D by MNEs is growing rapidly, most businesses still exhibit substantial home bias in their research 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).

The other side of this coin is 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. This has offered new opportunities for regions and cities to link up to different parts or functions of GVCs in ways that promote economic upgrading and innovation (Crescenzi, Harman, and Arnold, 2019). The off-shoring of R&D activities – as part of the expansion and re-configuration of GVCs and GPNs - has created new inter-connected architectures of innovation and research (Massini and Miozzo, 2012; De Backer, 2011; Schmitz and Strambach, 2009) as well as new co-location patterns with production activities. The simple nation-based host-home dichotomy largely applied in the academic literature to the MNE question therefore has become less useful in relation to knowledge flows. 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 (Crescenzi and Iammarino, 2017; Iammarino and McCann, 2018).

At the same time participation in global networks is a challenge for weaker regions. Uneven participation in GINs and GVCs 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., 2019).

There is a paradox in this global division of innovation activity. While dispersion would allow for deeper specialization, with MNEs being able to tap into localized specialties through global networks, different technologies are less nationally concentrated than they used to be. Figure 3 shows the Herfindahl-Hirschman index of patent filings by technology class across countries. A higher index indicates that patenting in this class is more concentrated within a small number of countries, while a lower index suggests that patenting is more evenly spread across countries. In almost all technology classes, concentration has fallen markedly over the last 1.5 decades. This mirrors developments in international trade discussed earlier: growing intra-industry trade suggests a lower degree of specialization within countries. To come back to the patenting picture in figure 3, it suggests that more countries are active in a wide range of technologies, perhaps all with their own niches that are connected through GINs.

[Figure 3 around here]

The globalization of innovation is the interface "between the two fundamental phenomena of modern economies: the increased international integration of economic activities and the rising importance of knowledge in economic processes" (Archibugi and Iammarino 2002, p. 100). 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).

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 (Crescenzi & Iammarino, 2017). Local technological competences are only important for attracting emerging market FDI if the prospective subsidiary will engage in technology intensive activities (Crescenzi et al., 2016b). Chinese OFDI is growing rapidly, notably since the financial crisis, which Chinese businesses survived relatively unharmed (Davies, 2010; Wei, 2013).

5. The Concentration Process: Innovation in Urban Hotspots and Specialized Niche Clusters

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 principally confined to some urban areas in some countries. 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. Yet, there was a period from about 1940 to 1980, where such geographical concentrations diminished, and innovation spread within the advanced economies. 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 et al., 2007).

In the global context, figure 4 shows the massive shifts in the global geography of innovation between the 1990s and 2010s. Between 1990 and 1994, California was by far the most important innovation hotspot in the world. However, beyond that, there were many North American and European regions – as well as Southern Kanto in Japan – with relatively similar levels of patenting, at around a third of the size of California. Many traditional manufacturing regions, such as North Rhine Westphalia, Pennsylvania and Ohio were among the top innovating regions.

This changed dramatically within twenty years. The lower panel of figure 4 shows the top patenting regions in 2012 to 2016. California was overtaken by Southern Kanto and Guangdong. The top three are followed with a small gap by the capital region of Korea, Kansai, Toukai (both Japan) and Beijing. Only then appear the next North American and European regions, including Bavaria, Baden-Wurttemberg, Texas and Massachusetts. This illustrates both the global spread of innovation to newly emerging East Asian hotspots, as well as the relative decline of innovation hotspots that were also manufacturing clusters.

[Figure 4 around here]

5.1. From sectoral to functional specialization

In the First and Second Industrial Revolutions, innovation activity was often strongly co-agglomerated with leading production activities, resulting in large, sectorally specialized industrial cities that also co-located R&D and product development. Since 1980, however, these patterns of co-agglomeration have changed. Co-location patterns 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). As a result, leading innovative urban agglomerations today appear functionally specialized 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).

We showed above that the patenting activity of countries has become less specialized, implying that most countries engage in a wider variety of different technology classes. Looking at individual hotspots, more subtle differences emerge, as shown in figure 5. The figures show the shares of broad technology classes of filed PCT patents. Note that these do not sum up to 100%, as patents can be filed in more than one class. The figure shows the largest hotspots over the 2012-2016 period. There are several, and in particular the largest hotspots, that exhibit growing specialization in the electricity and physics classes, such as California, the Capital Region of Korea, Guangdong and Washington State. Southern Kanto, Kansai, Bavaria and Texas are more diversified.

[Figure 5 around here]

As noted, Europe and the USA are a good contrast in granularity, with the USA having a smaller number of generally bigger innovation clusters than Europe (Crescenzi et al, 2007). Moreover, the landscape still contains some more traditional types of clusters in capital-intensive sectors such as mining, mechanical engineering, petroleum, shipbuilding, and aerospace. These generate agglomerations that combine core engineering-production tasks with core innovation tasks, Texas being a good example of this.

This shift from a larger number of sectorally specialized clusters towards a smaller number of specialized innovation hotspots becomes evident when looking at the overall concentration of patenting. Table 1 shows the Herfindahl-Hirschman index of patent concentration across NUTS3 regions, as well as the share of the largest region in total national patenting. For China and South Korea, the 1990 values should be taken with a grain of salt, as there was little patenting overall. It should also be note that comparability of magnitudes of these indicators across countries is difficult, because of the differences in size and number of regions. There are clear differences in trends, in particular between Europe and the US. In Europe, concentration is low. The HH-index is falling slightly over the period, while the share of the top region is increasing slightly. In the US in contrast, both the HH-index and the share of the top region (California) is rising significantly. The increase in concentration is even larger when focusing on ICT classes in the bottom panel. Looking at Germany separately, there is some fluctuation over the period, but no trend, except for ICT patents, where concentration is increasing somewhat.

Looking at the Asian economies, there is an uptick in concentration in Japan in the last period. In South Korea, regional concentration of patenting remained stable over the period, rising only slightly for ICT patents in the last period. In China, concentration of patenting locations decreases only slightly over the last two periods, despite a big push of industrialization from the coasts to the interior provinces (Wei, 2013). As in the US case, this illustrates the increasing independence of innovation from manufacturing activity.

[Table 1 around here]

The type of multi-sectoral but functionally specialized innovation clustering of the 3rd industrial revolution generates a problem with theoretical terminology used to capture urban productivity and innovation dynamics. In the classical terminology, we distinguish between a sectorally-specialized (vertical supply chain) agglomeration (Marshall) and a diversified, multi-sectoral (horizontal) agglomeration (Jacobs). Finally, there are "Marshall-Arrow-Romer" agglomeration effects due to localized learning, which opens up the question of whether learning is more effective in sectorally specialized or diverse agglomerations, those with, organized hierarchy or informal interaction, or – most recently – those that are functionally specialized but sectorally diversified.

In this light, many of the top innovation clusters discussed here are not neatly captured by the traditional concepts of specialization and diversity. In response to this gap, new ideas have been advanced, among which the most prominent are "related diversity" and "related variety" (Frenken, Van Oort and Verburg, 2007; Neffke, Henning and Boschma, 2011). They posit that clustering of a firm using related technologies involving many different output sectors can create synergies in the use of certain basic innovations to innovate into related areas or related varieties of outputs. From the standpoint of spatial economics, such clusters would be considered "specialized," but not sectorally specialized. Balland, Boschma, Rigby, and Roesler (2019) 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.

In evolutionary economic theory and theories of technological change, previous technological or organizational endowments have a strong role in shaping subsequent capture or creation of innovation (Nelson and Winter, 1982). 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). Chinitz (1961) made a more subtle argument about the qualities of previous regional economic endowments. In his account, 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. Most established innovation systems depend on historical industry concentrations and social linkages (Moulaert and Sekia, 2003).

5.2. Innovative clusters as development policy

Policy makers keen to spread the employment generating and productivity enhancing effects to lagging regions have long sought to create new clusters away from established innovation hotspots. Yet, 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, Glaeser and Kerr, 2011). 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). As in the natural world, firms form ecosystems that are not easily transplantable or reproducible (Ascani, Crescenzi and Iammarino, 2012). Anchor institutions such as universities and MNEs may be important factors in generating innovative agglomerations, though the presence of a university in itself is not enough in and of itself (Arora, Cohen, and Cunningham, 2018; Faggian and McCann, 2009).

As discussed above, innovative activity may have a natural tendency to cluster and concentrate. To balance the investments in research and development undertaken by businesses, many European governments target public innovation funding towards regions that receive less private investment (Forth and Jones, 2020). Nonetheless, the evidence in figure 6 points to the growing importance of hotspots. By 2016, 35% of all global PCT filings originated from just 5 regions. More than 10% originated from only one region. These trends are even more evident for ICT patents. The share of the top five regions increased steeply in recent years, to over 50% in 2016.

[Figure 6 around here]

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 several cases of successful government intervention to generate clusters in technologically-emerging economies. For example, in 2008, the municipal government of Chongqing, China, 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. 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. However, this is a cluster that was moved, rather than growing from scratch. The IT cluster in Bangalore, India was incubated by investment in India's space program, and then grew, supported by local investment in infrastructure and human capital (Gao, Dunford, Norcliffe, and Liu, 2018).

Indeed, while figure 6 above showed the impressive dominance of a few hotspots, figure 7 shows that in terms of overall patenting growth, there is a lot of dynamism outside established the biggest hotspots. The graph shows the growth in patenting (the height of the graphs), split by the largest hotspots and world regions (the colored blocks). The upper panel shows all patents, while the lower panel focuses on ICT classes. The top panel shows that for total patenting, hotspots contribute less than half to total patenting growth, and the hotspot share has remained relatively stable. There has been a shift in the distribution across world regions though, with Asia overtaking Europe and North America in total patenting growth. For ICT classes, hotspots play a larger role, contributing around two-thirds to total patenting growth. By far the largest single contribution during the last period is from Guangdong, where total patenting growth outstripped that in all of North America.

[Figure 7 around here]

6. Synthesis: The Geography of Innovation and Inequality, and a Research Agenda

There is considerable evidence of a positive relationship between innovation productivity and its spatial concentration and specialization. However, 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 and social income inequality. While high-skilled jobs create many low-skilled jobs in the home market (Moretti, 2012), inflows of high-earners combined with inelastic housing supply often result in growing inequality and falling disposable income for low income households. Ultimately, this leads to increased – whether at intra-metropolitan or inter-regional scale -- 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). Some evidence suggests that this is compensated to some extent by social mobility and opportunity for the less skilled who live in the more dynamic but unequal and segregated metropolitan areas (Chetty, Hendren, Lin and Majerovitz, 2016). We still know too little about the geography of positive and negative effects of these kinds of inequalities and how they unfold over generations.

Concentrating innovation in a smaller number of bigger and more specialized regions at both national and international scales can possibly raise the overall economy-wide rate of innovation. But if innovation activity concentrates, then other regions may be deprived of the possibility of becoming innovative in the future (Feldman and Storper, 2018; Feldman, Guy, and Iammarino, 2019). 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. However, 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.

6.1. Is innovation for winners only? Are current innovation agglomerations too big?

The geographical concentration of innovation in global hotspots raises several related issues concurrent with an overall productivity growth slowdown observed in many countries, especially as compared to the heyday of the second industrial revolution (Gordon, 2014 and 2018). Moreover in the current period, which is usually seen as a highly innovative age, R&D productivity has been declining, reflected in an increasing unit cost of R&D outputs, when measured by technological performance of those outputs (Bloom, Jones, van Reenen and Webb, 2017). Concentration in bigger agglomerations of these less productive skilled innovation workers and their employers may partly compensate for the decline in productivity. Further evidence, though not tightly linked to the declining R&D productivity hypothesis, suggests that many new technology industries (especially the platform-based ones and finance) are oligopolistic (Feldman et al., 2019). This would allow us to square the increasing number and cost of innovative workers, due to declining R&D productivity, but made possible by oligopoly rents, part of which are passed through into wages. And the growing concentration and higher wage bills could be consistent with a declining labor share of wages in oligopolistic local economies (Benmelech, Bergman and Kim, 2019; Azar, Marinescu, Steinbaum and Taskar, 2017).

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 (Diodato et al., 2018). 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. To retain economies of scale in each of these activities, innovative clusters would have to become bigger by implication. This would in turn reinforce the overall geographical concentration of innovation and the observed tendency toward inter-regional income divergence (O'Sullivan and Strange, 2018; Iammarino and McCann, 2018). Nonetheless, we lack models of the spatial "granularity" (or divisibility) of innovation, 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 hence greater inter-regional inequality.

We therefore need much more investigation of whether the current size distribution and population of agglomerations reflect true productivity gains or oligopoly rents and whether the current spatial distribution is the efficient one or whether superstar innovation agglomerations are, to put it simply, bloated in size. One of the most difficult questions for geography, economics and development studies is to identify why innovative agglomerations arise and flourish where they do; and yet this is understandably of greatest interest to policymakers. 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" (Chatterji et al, 2011; Storper, 2018; Storper, Kemeny, Makarem and Osman, 2015).

To return to our opening statement, innovation is the essential motor of the economy, but once we consider its geographies and the causes of those geographies, it can be seen as a societally-embedded change process with complex indirect effects. The geography of innovation is ultimately not just about spatial distributions of innovation, but must engage debates about market structure, efficiency, rent-seeking, competition, and income distribution within and between countries.

7. Tables

Table 1: Trends in regional concentration by country

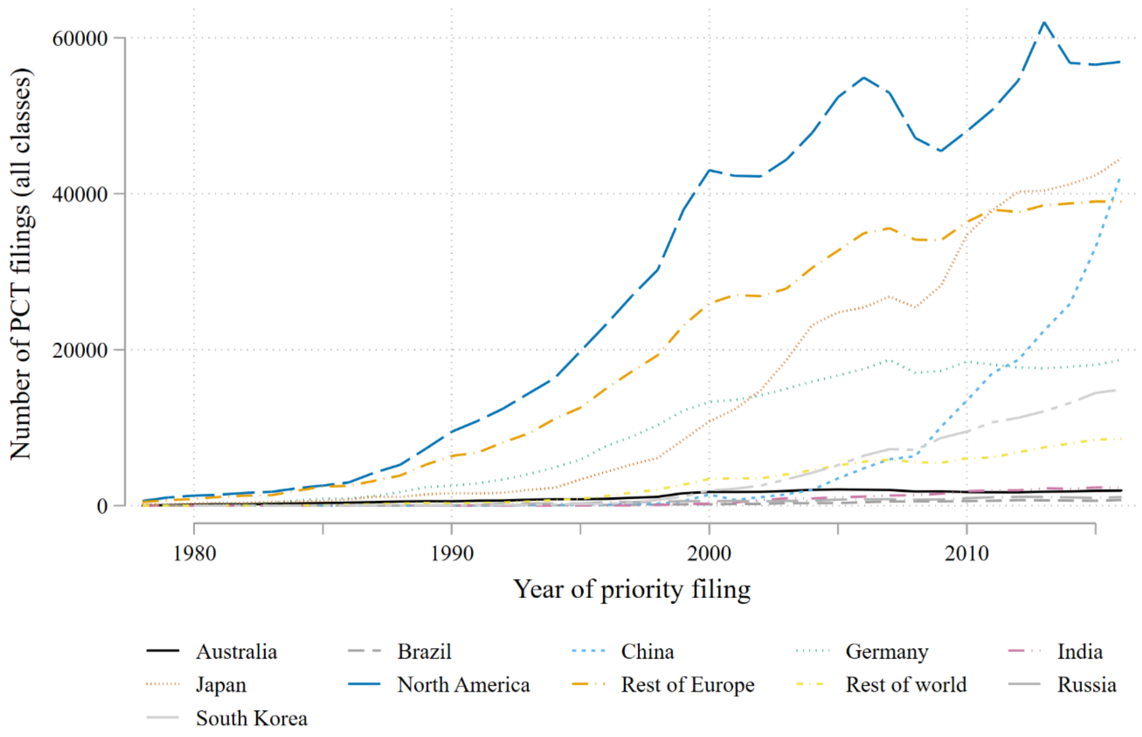
	All					
	1990		**2000**		**2016**	
	HH-index	**Top share**	**HH-index**	**Top share**	**HH-index**	**Top share**
China	41.21	60.1%	34.65	56.8%	31.03	52.7%
Europe (incl. Germany)	2.37	6.8%	2.23	7.0%	1.97	7.6%
Germany	17.58	26.7%	16.73	24.7%	18.15	28.7%
Japan	29.41	48.7%	29.76	47.7%	34.85	54.7%
South Korea	65.02	79.5%	50.64	69.1%	51.55	69.8%
United States	6.68	18.5%	7.98	23.1%	10.30	27.9%
	ICT					
	1990		**2000**		**2016**	
	HH-index	**Top share**	**HH-index**	**Top share**	**HH-index**	**Top share**
China	57.40	69.2%	19.20	32.0%	43.82	63.2%
Europe (incl. Germany)	4.02	10.0%	3.66	11.2%	2.57	9.1%
Germany	20.20	33.6%	24.64	44.1%	25.91	44.3%
Japan	44.04	63.5%	39.99	59.4%	43.96	63.7%

South Korea	100.00	100.0%	68.11	81.9%	71.41	83.9%
United States	10.93	24.5%	13.88	34.1%	22.77	45.3%

Note: HH-index is measured on a scale from 0 to 1000, 1000“Top share” is the share of patents from the region with the highest number of patents in that year.

8. Figures

Figure 1: Global PCT filings by country



	1980		2000		2016	
	Total filings	**Shares**	**Total filings**	**Shares**	**Total filings**	**Shares**
North America	1291	46.5%	43019	41.9%	56921	24.6%
Japan	278	10.0%	10822	10.5%	44546	19.3%
China	0	0.0%	1426	1.4%	42596	18.4%
Rest of Europe	855	30.8%	25926	25.2%	38985	16.8%
Germany	189	6.8%	13304	13.0%	18715	8.1%
South Korea	0	0.0%	1962	1.9%	14892	6.4%
Rest of world	11	0.4%	3445	3.4%	8576	3.7%
India	0	0.0%	268	0.3%	2372	1.0%

Australia	147	5.3%	1753	1.7%	1936	0.8%
Russia			586	0.6%	1125	0.5%
Brazil	7	0.3%	177	0.2%	733	0.3%

Figure 2: Country shares for different IPC sections

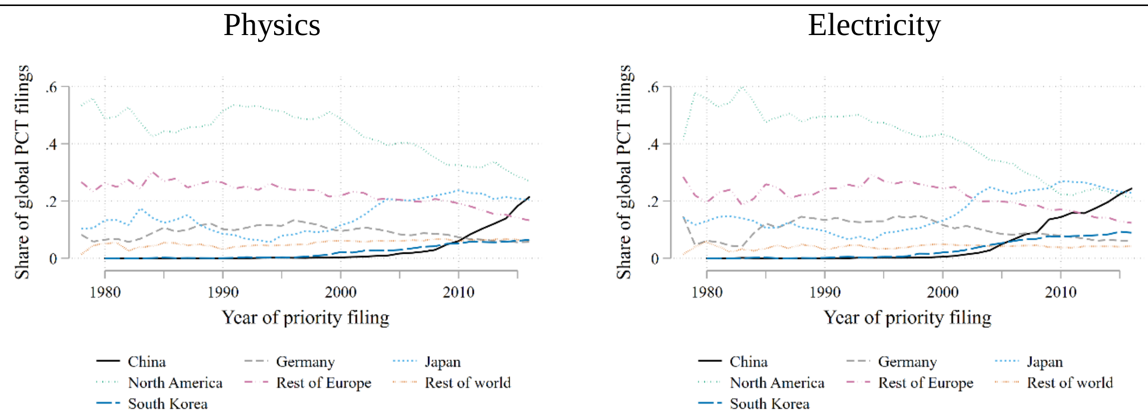


Figure 3: Global concentration of patenting by class

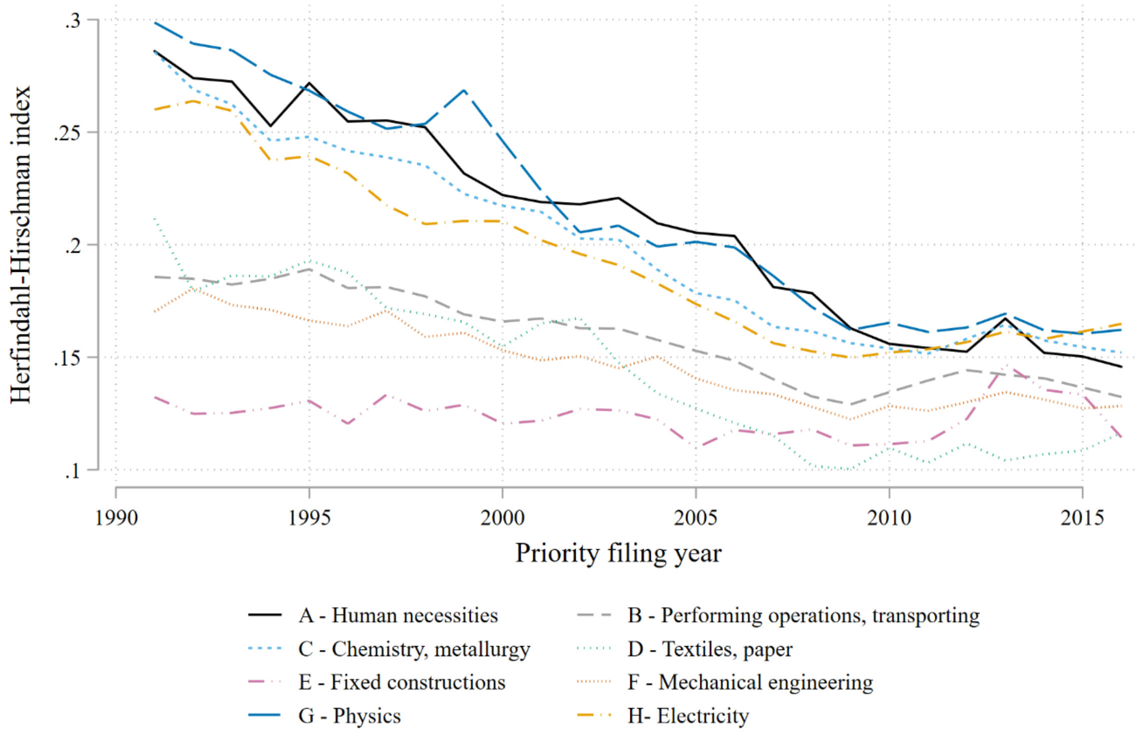


Figure 4: Global hotspots

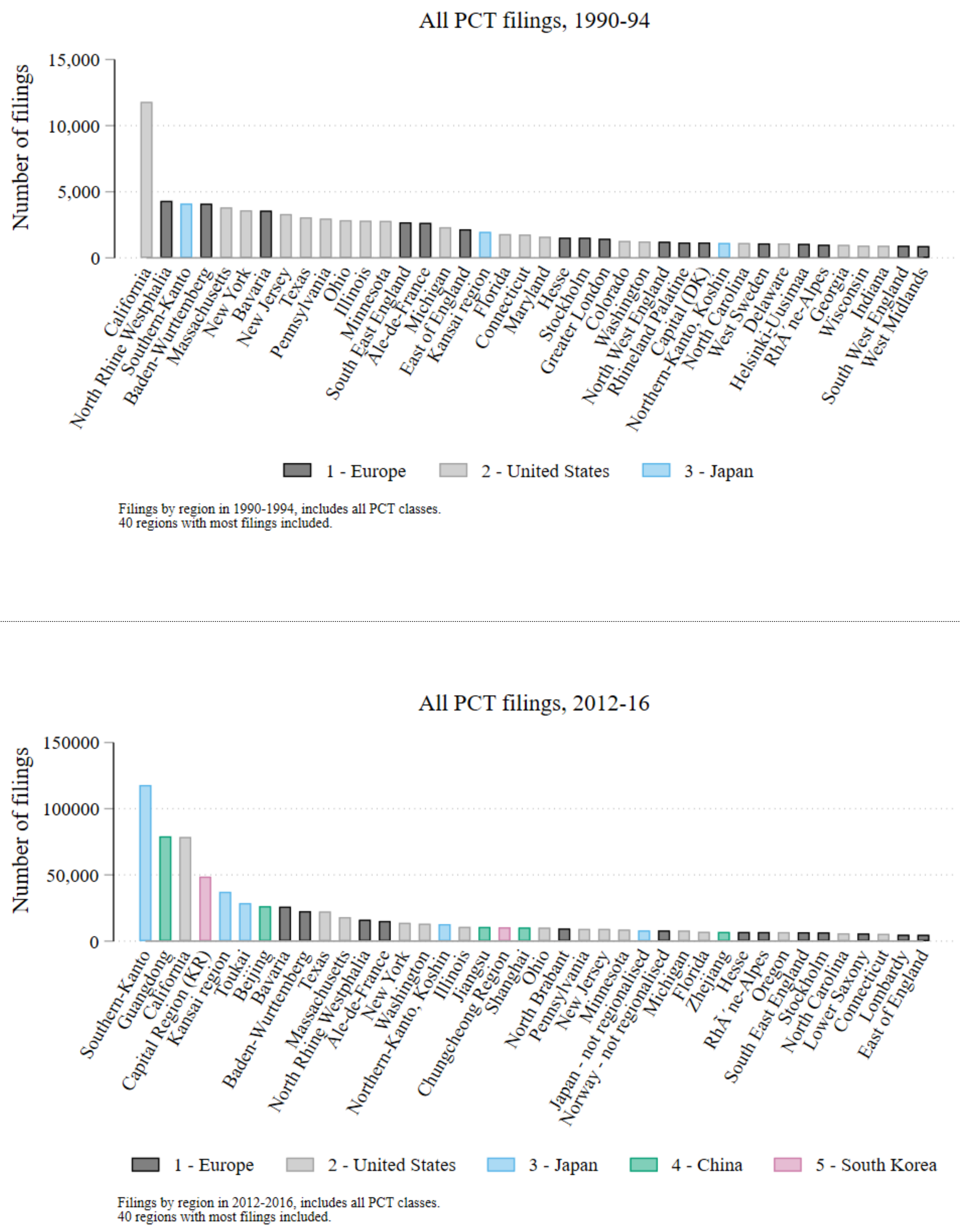


Figure 5: Technology specialisation of global hotspot regions over time

Figure 6: Share of global patents originating from hotspot regions

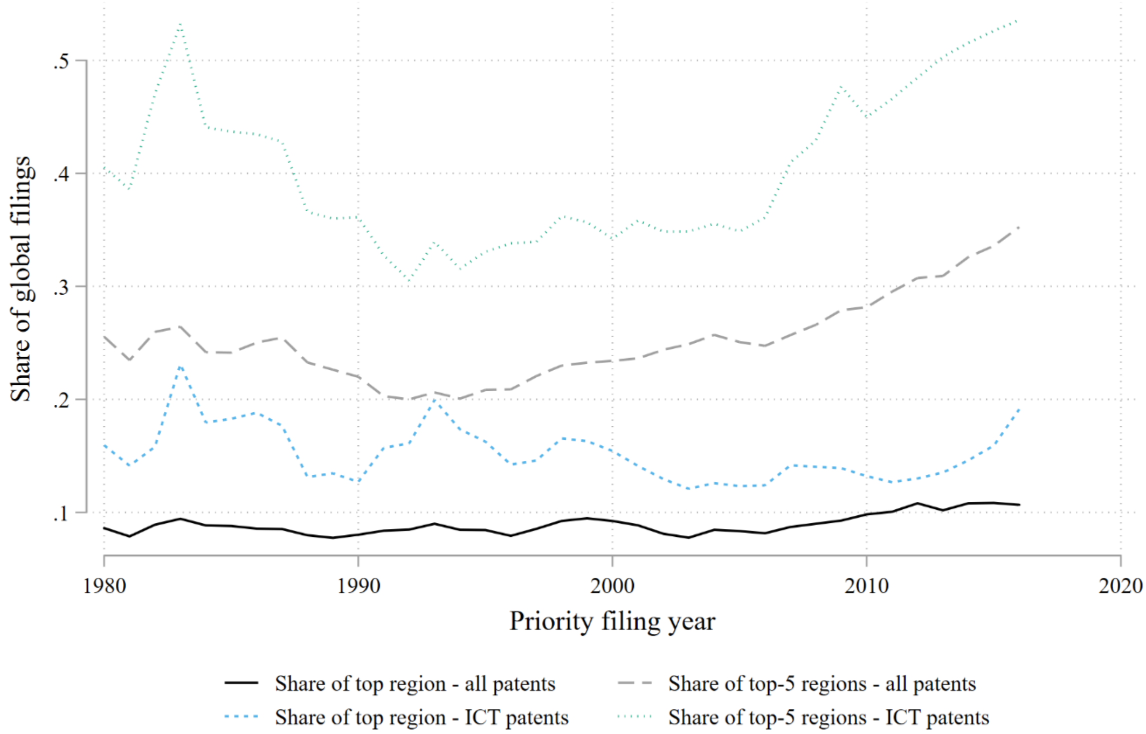
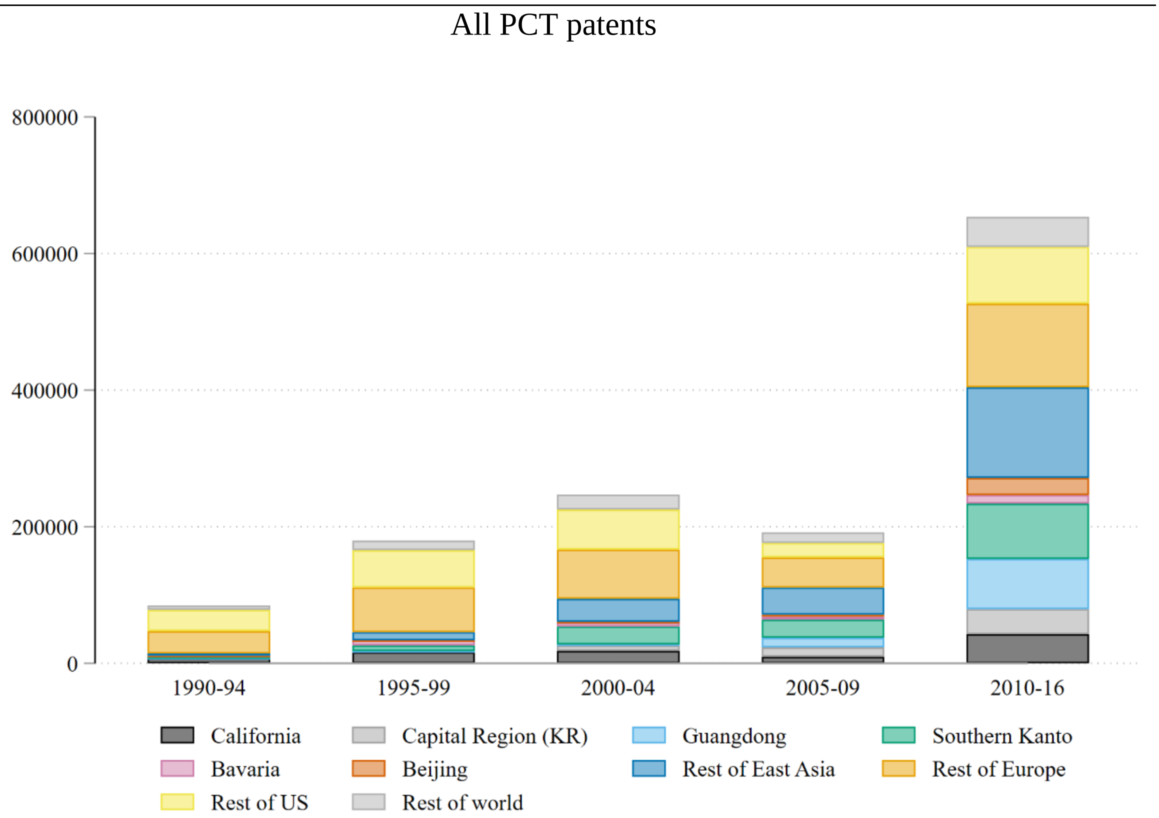
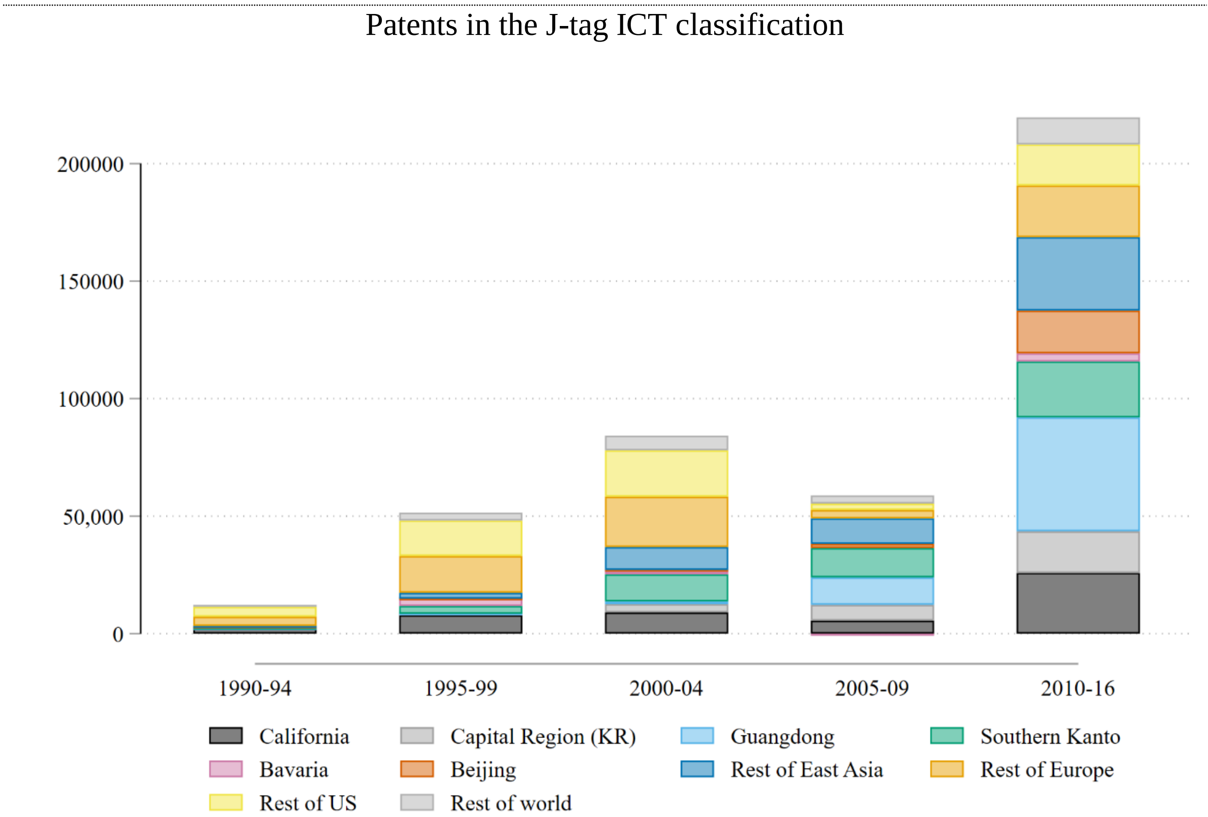


Figure 7: Which hotspots contributed most to global patenting growth?





9. Appendix

Figure A1: The "J-tag" taxonomy of ICT technologies

Technology area	Sub area	IPC
1. High speed network	Digital communication technique	H03K, H03L, H03M, H04B1/69-1/719, H04J, H04L (excluding H04L9, H04L12/14) *H04L9, *H04L12/14
	Exchange, selecting	H04M3-13,19,99, H04Q
	Others	H04B1/00-1/68, H04B1/72-1/76, H04B3-17 (excluding H04B1/59, H04B5, H04B7), H04H *H04B1/59, *H04B5, *H04B7
2. Mobile communication		H04B7, H04W (excluding H04W4/24, H04W12) *H04W4/24, *H04W12
3. Security	Cyphering, authentication	G06F12/14, G06F21, G06K19, G09C, G11C8/20, H04K, H04L9, H04M1/66-665, H04M1/667-675, H04M1/68-70, H04M1/727, H04N7/167-7/171, H04W12
	Electronic payment	G06Q20, G07F7/08-12, G07G1/12-1/14, H04L12/14, H04W4/24 *G06Q30/02
4. Sensor and device network	Sensor network	G08B1/08, G08B3/10, G08B5/22-38, G08B7/06, G08B13/18-13/196, G08B13/22-26, G08B25, G08B26, G08B27, G08C, G08G1/01-065 *G06F17/40, *H04W84/18
	Electronic tag	H04B1/59, H04B5 *G01S13/74-84, *G01V3, *G01V15
	Others	*H04W84/10
5. High speed computing		G06F5, G06F7, G06F9, G06F11, G06F13, G06F15/00, G06F15/16-15/177, G06F15/18, G06F 15/76-15/82
6. Large-capacity and high speed storage		G06F3/06–3/08, G06F12 (exclude G06F12/14), G06K1-7, G06K13, G11B, G11C (exclude G11C8/20), H04N5/78-5/907 *G06F12/14, *G11C8/20
7. Large-capacity information analysis	Database	G06F17/30, G06F17/40
	Data analysis, simulation, management	G06F17/00, G06F17/10-17/18, G06F17/50, G06F19, G06Q10, G06Q30, G06Q40, G06Q50, G06Q90, G06Q99, G08G (exclude G08G1/01-065, G08G1/0962-0969) *G08G1/01-065, *G08G1/0962-0969
8. Cognition and meaning understanding		G06F17/20-17/28, G06K9, G06T7, G10L13/027, G10L15, G10L17, G10L25/63,66 *G06F15/18
9. Human-interface		H04M1 (exclude H04M1/66-665, H04M1/667-675, H04M1/68-70, H04M1/727), G06F3/01-3/0489, G06F3/14-3/153, G06F3/16, G06K11, G06T11/80, G08G1/0962-0969, G09B5, G09B7, G09B9 *H04M1/66-665, *H04M1/667-675, *H04M1/68-70, *H04M1/727, *G06F17/50, *G06K9, *G06T11, *G06T13, *G06T15, *G06T17-19
10. Imaging and sound technology	Imaging technique	H04N (excluding H04N5/78-5/907, H04N7/167-7/171), G06T1-9 (excluding G06T7), G06T11 (excluding G06T11/80), G06T13, G06T15, G06T17-19, G09G *H04N5/78-5/907, *H04N7/167-7/171, *G06T7, *G06T11/80
	Sound technique	H04R, H04S, G10L (excluding G10L13/027, G10L15, G10L17, G10L25/63,66) *G10L13/027,* G10L15, *G10L17, *G10L25/63,66
11. Information communication device	Electronic circuit	H03B, H03C, H03D, H03F, H03G, H03H, H03J
	Cable and conductor	H01B11
	Semiconductor	H01L29-33, H01L21, 25, 27, 43-51
	Optic device	G02B6, G02F, H01S5
	Others	B81B7/02, B82Y10, H01P, H01Q
12. Electronic measurement		G01S, G01V3, G01V8, G01V15
13. Others	Computer input-output	G06F3/00, G06F3/05, G06F3/09, G06F3/12, G06F3/13, G06F3/18
	Other related technique	G06E, G06F1, G06F15/02, G06F15/04, G06F15/08-15/14, G06G7, G06J, G06K15, G06K17, G06N, H04M15, H04M17

Source: Inaba and Squicciarini (2017), table 2.

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