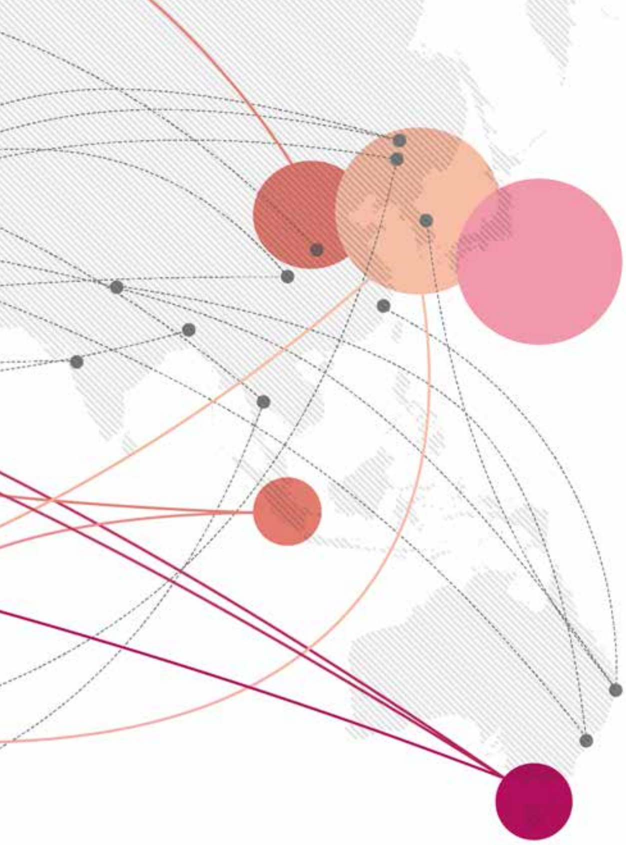
Chapter 1

The changing global geography of innovation

Technological innovation is the engine that propels economic growth and fosters higher living standards. As described in WIPO's *World Intellectual Property Report 2015*, the growth record of the past 200 years has been historically unprecedented. A series of technological breakthroughs have greatly improved the quality of life and generated widespread material prosperity. Even so, some national economies have seen faster and more sustained growth than others. The geographical distribution and the spread of innovation activities – whether technological or knowledge-generating – go a long way to explaining why some economies have developed faster than others. New technologies, in turn, have shaped where and how innovation has taken place.[1]



The first industrial revolution – spurred in the late 18th century by new manufacturing processes powered by steam – concentrated the world's industrial output in Western Europe, particularly, the United Kingdom (U.K.).[2] It changed the face of the world economy, generating a different global development hierarchy. Equally important, it also led to persistent regional divergences within Europe, with a select set of regions and cities – such as Manchester and London in the U.K., Normandy, Paris and Lyon in France, the Ruhrgebiet in Germany, Liège in Belgium or the Franco-German region that included Lorraine, Saarland and Luxembourg – constituting the "European core."[3]

The second industrial revolution – driven by a broad array of electro-mechanical inventions in the second half of the 19th century – witnessed the entry of North America into the high-income club of the world, while broadening the industrialized regions of Europe. There was not a perfect overlap between the countries, cities and regions at the core of the two revolutions. Some previously core regions declined while others thrived. In Europe, the waves of industrialization expanded concentrically, taking in, among others, southwest France, northeastern Spain, the Milan–Venice corridor in northern Italy, Berlin, Vienna, Krakow and Prague, as well as moving north to Oslo and Sweden's Gothenburg. In the United States of America (U.S.), northeastern cities – such as Boston, New York and Baltimore – remained industrially important, but industrialization expanded to several Midwest cities, such as Chicago, Detroit, Minneapolis and Cleveland.

Starting in the 1970s and 1980s, a third industrial revolution has occurred, broadly involving digital technologies, life-science and biological technologies, financial engineering and significant breakthroughs in transport and logistics. It has coincided with major increases in global trade and investment flows. Innovation and economic development has spread to northeast Asia, moving from Japan to the Republic of Korea and later to China. Tokyo, Seoul, Shenzhen and Beijing have grown into megacities shaping the direction of technological progress today. The "incumbent" high-income economies in Europe and North America continue to be at the forefront of innovation, but again with a new geographical landscape within them.

What forces can explain why innovation has concentrated in certain geographical areas and has spread only unevenly? Going beyond the broad patterns outlined above, how exactly is the global geography of innovation changing? How do companies in today's globalized age organize their innovation activities across the world?

This report endeavors to provide a perspective on these questions. It does so in three parts. First, it reviews economic thinking and empirical evidence explaining the geographical distribution of innovative activity – a task performed in this opening chapter. Second, it draws on patent and scientific publication data with geocoded inventors and scientific authors from around the world to show how this geography of innovation has evolved over the past decades. The discussion of the emerging trends – presented in Chapter 2 – will portray this geography in terms of global innovation networks (GINs), geographically concentrated innovation hotspots and niche innovation clusters connected to one another, which are increasingly leading the way. The report will also illustrate the operation of such GINs through two case studies – one on autonomous vehicles and the other on agricultural biotechnologies. These case studies will be presented in Chapters 3 and 4, respectively. Finally, the report concludes – in Chapter 5 – with policy perspectives on its main findings. They emphasize, in particular, the benefits of national innovation systems remaining open to the international exchange of knowledge.

This opening chapter discusses the main economic forces behind both the geographical concentration and spread of knowledge creation and diffusion. The following section reviews the main economic theories and existing evidence behind the geographical concentration of innovative activities. It shows that the processes of knowledge creation and flow, investment and appropriation are reinforcing global innovation and economic hierarchies and how they are concentrating innovation within geographical hotspots or clusters, most of them metropolitan. Section 2.2 considers how these processes are at the same time leading to an increased dispersion of hotspots at a global scale. It explores the main forces – operating principally through global networks of firms, researchers and entrepreneurs – which are linking the main innovation-creation centers around the globe. The final section explores some of the consequences arising from today's global network of highly concentrated innovation hotspots.

1.1 Concentration of innovation in urban hotspots

Framing the geography of global innovation requires understanding both the forces driving innovation's concentration and its spread. One prominent feature of the geography of economic development is common to both established high-income economies and successful emerging middle-income ones: the geography of high incomes is increasingly metropolitan, reflecting renewed inter-regional divergence within countries. These metropolitan areas are also hotbeds for the formation of ecosystems of innovation. In the U.S., two prominent examples are the southern part of the San Francisco Bay Area in Northern California and the Greater Boston metropolitan region in Massachusetts, often dubbed *Silicon Valley* and *Route 128*, respectively.

What economic forces explain the agglomeration of innovation?

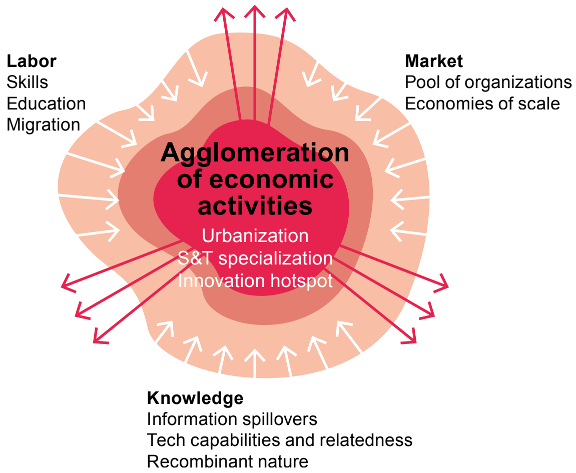
One of the toughest questions for geography, economics and development studies is to ascertain why such hotbeds, or agglomerations, of innovation arise and flourish where they do. This question goes from the general factors that lie behind the clustering of innovation to the specific geographies of those agglomerations.[4]

Several different economic theories address this question. These most commonly consider the economic forces relating to pools of skilled labor, market scale and knowledge spillover – where highly innovative firms are concentrated, knowledge can filter, or "spill," from one to another. Historical accidents or deliberate policy can affect all these, but none succeed entirely in answering the question. At the same time, there are forces pushing in the opposite direction, toward geographical dispersion, but all accounts indicate these are not as a strong.

Figure 1.1 provides a graphical summary of the main forces driving concentration, discussed below.

People, companies and ideas cluster together

Figure 1.1 Main economic forces driving geographical concentration of innovation



Note: S&T = Science and technology.

Does skill supply help drive innovative agglomeration?

Mainstream economic theory offers a number of ways in which the geographical concentration of innovation can be an indirect outcome of labor supply – both quantity and quality.[5]

These theories assume that workers with different skills gravitate toward different regions. In basic terms, highly skilled workers cluster together, because they want to interact with one another, so the education and skills of the workforce in a given region can act as a force of attraction. At the same time, migration can change the skills base of the workforce of the receiving region, reinforcing the agglomeration effect.

The preferences of highly skilled workers for vibrant agglomerations and to work in innovation are part of this picture. Innovation-generating occupations offer career trajectories and life-long learning, which secure future employment opportunities at a time when automation increasingly seems to threaten many traditional white-collar occupations. Such work also offers high wages that compensate for rising costs of living and housing. Cost pressures also push less well-paid, unskilled workers to the urban periphery.

Empirical evidence shows that regions that had a higher-than-average concentration of college-educated workers in the past observe further growth in the share of college-educated workers, per capita incomes, patents and other direct and indirect proxies for innovation. The characteristics of the local labor supply seem to influence the development trajectory of innovation-generating agglomerations and impact regional innovativeness, both in the U.S. and in the European Union (EU).[6]

However, what explains the origin of a singularly skilled workforce in a given region? At some points in history, skilled workers have changed their geographical distribution, favoring spatial spread. Why has the behavior of the skilled workforce spontaneously changed in favor of geographical concentration? This was the case in the maturing phase of the second industrial revolution, when there was a massive migration of skilled workers – together with unskilled ones – from all over the world to the leading developed countries from 1940 to 1980.[7]

Historical accidents involving unusual individuals can be partial explanations for the location of innovative agglomerations, especially those involving first-mover regions in the key technologies of each industrial revolution. Thus, by 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. Another anecdote concerning Shockley is that after he attracted top-quality associates to his first-mover firm, his difficult management style caused them all to quit on the same day. This event – known as "Shockley's massacre" – created a first and unexpected example of the spin-offs that have become so typical in the Silicon Valley process of development. The annals of innovation contain plenty of other such people-based stories.

Nevertheless, the randomness of such "great inventor presence" stories raises some doubts. There are so many famous individuals associated with Silicon Valley – from Shockley and Frederick Terman, one of the acknowledged "fathers" of Silicon Valley, to Apple's Steve Jobs and Google co-founders Sergey Brin and Larry Page – that it seems unlikely that all could be there by coincidence. Moreover, Saxenian (1994) powerfully argues that the mere presence of early innovators is not enough. Plenty of the early great information technologies (IT) innovators were located in Boston, but they did not stay. Facebook's 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.

In addition, "skill" is not a uniform entity and different technologies may need different sets or combinations of skills that may not always overlap. A finance worker will be attracted to different locations than an IT engineer, and these locations and jobs are not interchangeable. But at the same time, different professions and skills may be complementary for the production of a given innovation.

Demand side: how market forces generate innovation hubs

Market economic forces complement labor supply ones as drivers of the geographic concentration of innovation activities. The main market economic forces are generated by the "pool" of organizations – notably private firms – within a market and the consequent economies of transport, scale and scope.

This pool is at the heart of productivity differences across regions. As with the "unusual individual cases," historical accidents involving innovation breakthroughs by a key firm within a local economy, a so-called "anchor" firm, can be equally important in starting an innovation ecosystem that then organically grows as both skilled labor and related activities relocate. At such moments, key firms can have an idiosyncratic influence on agglomeration. But this is not always the case. Motorola located the largest early semiconductor facility in the world in Phoenix, Arizona, in the 1950s, for example, but this did not establish that U.S. city as a subsequent center for IT industries.[8] Motorola had believed that it could be a geographically isolated first-mover in a technologically innovative industry. It turned out that only those first-movers that did not isolate themselves from the open source networks of the emerging Silicon Valley – such as semiconductor firm Fairchild and computer company Hewlett-Packard – were able to keep up with the rapidly rising technology curve.

Regions with industrial concentration benefit from more complete local labor markets. Firms can find specialized skills more easily, reducing costs related to employees' skill conversion or relocation. Similarly, a higher concentration of firms is more likely to generate new firms. These spin-offs are more likely to be more productive the higher the productivity of the original pool of firms. The agglomeration and innovativeness of the car industry in Detroit in the first quarter of the last century was due to a great extent to spin-offs carrying on the technological and organizational practices of their parents.

Academic institutions – such as universities – are also important factors in concentration. The concentration of university graduates and science, engineering and technology workers mirrors the spatial concentration of innovation activities. In the U.S., skilled workers, particularly in the services sector, relocate to larger cities and away from small and medium-sized ones. Academic research is also more productive and creative – i.e. more unconventional – in larger and more diverse agglomerations.[9]

New theories of economic geography have extended and perfected the argument of the pool of organizations. Unlike most traditional spatial analysis, they identify geographical concentration as a snowball process whereby regions progressively draw in supplier firms and human talent. In its simplest version, regional differences in productivity or economies of scale alone can explain the divergence in geographical concentration between two equivalent regions, or explain the reinforcement of the concentration in core regions vis-à-vis the periphery. The basic mechanism is that any confirmed difference in productivity or innovation levels in a given region accrues to generate or confirm the leading position of the more innovative or productive region.[10]

According to these theories, agglomerative market forces are at work when both firms and consumers can take advantage of clustering in one location. Agglomerations with large local markets are preferred sites for the production of consumer goods due to the economies of transportation, scale and variety. Transport economies are in place when local firms can serve a large local market faster and cheaper than distant ones. Similarly, firms supplying large markets benefit from economies of scale by splitting the sunk investment costs over more units sold and optimizing production processes through several iterations. Consumers in larger markets enjoy a higher variety of goods. Not only can consumers find the exact variety of product they are looking for in a larger market, firms can specialize in delivering it. These three mechanisms – transport, scale and scope – also affect firms producing intermediate goods locally, which reinforces economies downstream in the local supply chain.[11]

Do knowledge spillovers and technological conditions attract concentration?

But market scale and the availability of a skilled workforce do not lead straightforwardly to a region mastering the next wave of innovation. Advantages obtained from previous successful innovation processes do not assure future technological advantages.

As with large markets and complete labor markets, so-called information and knowledge spillovers are also positive externalities favoring co-location of innovative firms, academic centers and talented human resources.[12] Knowledge is not restricted to the technological and organizational practices of an existing organization or individual; it may spill from one to the other. Firms more successfully exploit economies of scale and scope if they learn from the experience of other firms. Skilled workers disseminate tacit knowledge when they interact with other skilled workers, change organizations or migrate.

Most empirical evidence points to knowledge spillovers being extremely geographically concentrated. This is mainly due to the high costs associated with codifying, exchanging and absorbing knowledge. While information, such as data, flows increasingly freely across organizations and regions, spillovers of knowledge – what is needed, for example, to interpret data – are "stickier." Firms, academic organizations and individuals have to actively interact, collaborate and, sometimes, move to make knowledge flow. The concentration of knowledge spillovers can, therefore, be both a consequence and a trigger of the agglomeration of innovation. Innovative firms will move to where knowledge spillovers are higher, reinforcing spillovers in that region and crowding out non-innovative firms to the periphery.[13] This joint innovation and spatial co-evolution can determine a regional development path, which can be largely irreversible.

While previous regional technological endowments are likely to shape subsequent creation of innovation, not all innovative regions follow the same trajectory. In the 1930s, both Princeton, New Jersey – site of RCA Laboratories – and Silicon Valley were home to close technological antecedents of the IT industry; but they developed very different innovative paths. Silicon Valley's remarkable IT innovation trajectory grew out of the pre-existing and mutually supporting manufacturing industries of power grid tubes, microwave tubes and silicon components. These industries enriched the northern Californian IT innovation ecosystem with related technological capabilities and new management approaches easily transposable to the nascent IT industry. Princeton and other East Coast hubs had a much narrower technological IT ecosystem based on few large companies.[14]

In this sense, more diversified agglomerations have a greater probability of successfully transitioning to a new technological capability than narrowly specialized ones.[15] The literature abounds with stories of how narrowly specialized economies are locked into their technologies and do not transition after negative demand shocks or technology shifts. It seems that technological innovation is more likely to occur in regions with a broader portfolio of technical competences, especially when it is easy to recombine these. Dominant industries tend to monopolize talent, supplies of economic factors of production, such as capital or entrepreneurship, and attention. Such resource concentration potentially crowds out other activities and can channel the evolution of regional economies down different pathways. For instance, Detroit – the "Motor City" – is held up as a case of over-specialization. And yet there are highly specialized centers of mechanical engineering and automotive technology that have mastered subsequent waves of technology, such as Stuttgart in Germany. Boston was once narrowly specialized in mill-based industries, but is now a high-tech center. The capacity for regional economic evolution is governed by possibilities for moving into related varieties of technologies and technological capacity.[16]

However, technological relatedness and complementarity are not the entire story. There are many examples of regions that capture major new sectors with little technological relation to their previous activities. Los Angeles was not a major mechanical engineering region in the 1920s and 1930s when it became the aircraft-engineering center of the U.S. and, by the 1940s, the world's biggest aerospace cluster. Los Angeles also had no 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 U.S. car technology and manufacture.

In these, and many other examples, there were technological windows of opportunity. These ruptures in technological relatedness largely obviate the advantages of pre-existing agglomeration and create a relatively flat playing field for a short time in the early days of a technology's existence.

To sum up, the interaction between innovation and geography reflects the juxtaposition of individual, organizational and technological antecedents. Saxenian's (1994) seminal comparison of Boston's Route 128 and Silicon Valley shows that the types of entrepreneurship, production organization and system coordination experienced by existing firms and actors in a region will shape how that region evolves economically and what kinds of new activities it can generate and capture.

Can policy mold the forces of innovation agglomeration?

There is little systematic, large-scale evidence for 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. Government subsidies might actually attract the "wrong" kind of firms that have low productivity and depend on subsidies for survival or which are not in fact open to creating networks among local firms for fear of leaking intellectual property (IP). Because of the path dependency of industry growth and cluster creation, it is questionable how much policy can achieve. As in nature, firms form innovation ecosystems that are not easily transplantable or reproducible, as they develop embedded in territorially-specific institutional settings and social fabrics.[17]

Nevertheless, the above does not mean that all policy has failed in influencing cluster formation. Indeed, a common feature of any national innovation system is that market forces of agglomeration are not the only factor shaping the geography of innovation. The public sector, as well as the higher-education sector and academic institutions are also key actors that shape the innovativeness of countries and regions. This is particularly true in developing economies where public investment is the main driver of research and development (R&D) expenditures.[18] A variety of circumstances motivates public sector support for innovation. In some countries and regions, stagnating productivity has stimulated a revival of industrial policy. In many of the most successful former middle-income economies, industrial policy with a strong innovation component was in evidence during their economic ascent.

In the U.S., a notable successful policy story is the Research Triangle Park in North Carolina. While perhaps not equivalent to Boston or Silicon Valley, the Research Triangle Park is known as a leader in a wide variety of high-tech fields and as a model of one of the first and most successful research parks.[19] Public policy can also affect the geography of innovation more indirectly through the R&D system and, in particular, the role of universities and public research laboratories and organizations. In the U.S., from 1875 to 1975, the federal Land Grant Colleges system extended the geographical spread of research universities, while federal funding for universities reinforced the proliferation of universities. The California system is perhaps the most successful of all, with the public University of California system having six of the world's top universities. The same applies to the geographical distribution of public sector laboratories, such as the national laboratories in the U.S. or the *Conseil National de Recherche Scientifique* (CNRS) labs in France.

Analogously, most of the former middle-income economies that are now high-income and highly innovative regions of the world – such as the Republic of Korea, Singapore or Israel – made a successful effort to build top-ranked research universities.[20] In China, it seems likely that the appearance of top world innovation clusters is related to the investments in top world research universities.

There are also selective examples of successful government intervention to generate clusters in middle-income 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. Their policies targeting investments in infrastructure, labor market organization and other business-friendly actions incentivized new businesses, initiatives and entrepreneurship. However, the policy moved existing clusters rather than growing new ones organically. Other initiatives in China have taken different approaches, depending on the capabilities and powers of the local administration. India's investment in a space program located in Bangalore incubated an IT cluster in the same area. Then, with the policy support provided by investment in infrastructure and human capital, the new cluster grew organically. All of these clusters started as manufacturing hubs and became innovative to varying degrees as the manufacturing phase matured. But the process also involved a significant contribution from multinational companies, whose role in global innovation networks will be examined below.[21]

All the public investments required to carry out such strategies are large and must be long-term and appropriately institutionally organized. However, there is an inherent tension between inter-regional equity and the excellence that is present in virtually every large country with a public higher education system today. As it is not practical to have equally well-endowed research universities in every locality, any successful innovation policy eventually leads to some internal concentration.

In addition, in today's agglomerated innovation environment, certain public sector institutions – especially universities – are strongly reinforced by market forces that make some more attractive to students, faculty and funders. This reduces the efficiency of public sector policies for spreading innovation around different regions and 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. Unfortunately, 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.

Other policies – or a lack of these – can also indirectly affect the forces behind the agglomeration of innovation. The preferences of highly skilled workers, entrepreneurs and innovative companies for certain agglomerations may reflect deliberate cluster policies, but they are also not unconnected to tax, social security and education policies, among others.[22] For instance, successful innovative regions with highly unregulated real-estate markets will likely observe a housing price uptick, which will exclude low-skilled workers and drive them to regions with lower-cost housing, as noted above.

Why do geographical concentration and spread coexist?

Threaded throughout the discussion above there is considerable reference to regional concentration within a process of global dispersion. This is the other major defining characteristic of the contemporary geography of innovation. While innovation activity is increasingly concentrated in metropolitan areas, it is also gradually spreading to hubs outside the traditional centers in the U.S. and Western Europe.

The empirical evidence simultaneously points both to the importance of the increasing global nature of innovation and to the growing forces driving the agglomeration and concentration of innovation in specific – often metropolitan – areas. Rather than being antagonists, these trends are complementary, 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. The world system of innovation links national systems of innovation and global firms through a spiky geography of knowledge creation. The result is 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.

International openness is a distinctive trait of leading agglomerations of geographically concentrated innovation today. But 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 along such knowledge exchange. In the past, however, such exchanges often involved the display and then possible imitation of what was created in a rival agglomeration.

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 dispersed and global networks of innovation.[23] 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 a region through the establishment of these linkages. Innovators rely on collaborations both inside and outside the organizations and the regions where they work.

These networks of geographical spread of innovation will be discussed in the following section.

1.2 Networks and the global spread of innovation

In recent decades, global networks for the production and delivery of goods and services have expanded greatly. In comparison to previous globalization waves, the current globalization has a much higher proportion of intra-industry exchange of both components and final goods within global value chains. Prior to 2000, most of such intra-industry trade took place among a few countries, most notably in the northern hemisphere. But since then, it has more and more concerned the relationships between developing economies and the rest of the world. Global production networks often involve multiple or circular trade flows, with exports wrapped into subsequent outputs and ending up as imports, blurring the line between foreign and domestic production.[24]

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 underlying innovation networks and ecosystems, which are both a consequence of global productive integration and, increasingly, a cause of it.

Mirroring the growing globalization and complexity of production systems is an increasingly dispersed and complex plumbing system for knowledge production. The globalization of innovation is a result of an increased international integration of economic activities and the rising importance of knowledge in economic processes.[25]

From the mid-20th century until the Great Recession, beginning around 2008, technological activity was also steadily internationalizing, with new countries emerging in the international system of innovation. More recently, there is some evidence of the selective reshoring of some key R&D and innovation activities back to home countries. At the same time, however, the post-recession period has seen a growing articulation of value chains beyond national borders, involving an increasing share of intra-firm trade flows, with the knowledge flows they entail.[26]

What economic forces explain the spread of innovation?

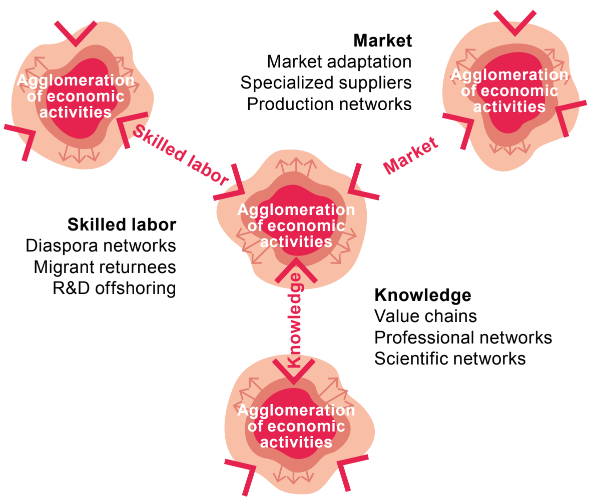
The economic forces driving the spread of innovation are very similar to those stimulating its concentration in specific clusters. Economic agents in a given innovation hotspot spread innovation to other regions of the world and vice-versa, which is why the spread of global innovation can be thought of as a bidirectional network of knowledge and technological flows.

It is worth recapitulating that the geographical spread of innovation to peripheral areas of a region or country is often limited, because the forces pushing for concentration are too strong. Nevertheless, the same strong concentration forces operating in one urban cluster are at work in others. This can lead to reciprocal relationships that generate a further spread of innovation and knowledge. Regions spreading and receiving innovation are likely to remain connected, but these knowledge and technological flows often skip the peripheral regions of the world and link directly to the main economic agglomerations.

Figure 1.2 sums up the three main bidirectional economic forces forging the links of an international or interregional network – market, skilled labor and knowledge.

People, companies and ideas link beyond geographical borders

Figure 1.2 Main bidirectional economic forces spreading innovation



The international and inter-regional mobility of skilled innovators is a key feature of the contemporary innovation environment, creating an interpersonal link between hubs. This mobility may positively stimulate the international dispersion of innovation by strengthening these innovation networks.[27]

The global diffusion of knowledge does not take place through random mobility of people, of course, but by their moving between places in which they are likely to find the right conditions and the right people to unleash their innovativeness. As noted, these networks serve not just as a means of dispersion and mobility, but as key points of attraction for the skilled. This talented workforce can reap learning and experience premiums by being in geographical hotspots with key network nodes and whose networks are deep. The ability to acquire more experience and improve skills is considered one of the main reasons why the skilled continue to move into the most expensive cities, in spite of high costs of living, contributing to the rapid growth in geographical differences in the wages of the skilled. Evidence that both international and inter-regional "brain drain" is at a very high level today complements this picture.

Labor mobility can take various directions. After concentrating in a region, skilled migrants often generate a diaspora network linking the origin and destination regions. Moreover, many highly trained migrants return to their original region to apply their higher skills there as entrepreneurs.

Saxenian (1999) explores the interaction of people and investment networks through the mobility of skilled Asian entrepreneurs from and to Silicon Valley. She explains how skilled workers come to Silicon Valley and acquire human capital and experience; they become integrated into local networks while continuing to maintain links back home. For example, Chinese and Indian U.S.-trained engineers coordinate activities between Silicon Valley technology producers and the manufacturing and design expertise in their home country regions. As skilled Asian entrepreneurs move around, they engage in knowledge-sharing, leading to what is termed "brain circulation." By drawing on their networks, they also seem to be able to facilitate investments in new business ventures, highlighting the parallel movement of networks and foreign direct investment (FDI) channels.

Equally, multinational companies (MNCs) relocating R&D sites offshore in order to benefit from an extraordinary – or cheaper – research labor supply also generate bidirectional knowledge flows, at least with the headquarters' region. Access to talent and R&D cost are among the main known MNC motivations to internationalize R&D. Global patenting is increasingly the result of the collaboration of large teams operating within the organizational boundaries of MNCs. For instance, a significant share of Chinese and Indian patents at the U.S. Patent and Trademark Office (USPTO) are the result of collaborations of this type.[28]

Market forces and role of MNCs in internationalization of networks

The forces at work in market agglomeration and spread create links within a firm, among different firms or across different organization types. For example, market size can make a firm relocate production to reduce transport costs and benefit from economies of scale. Technology transfers will necessarily be involved in putting in place the new production site, while inverse knowledge flows will also happen when adapting the product to local taste or regulations.

A key agent in all of these long-distance technological interactions is the multinational. In addition to access to lower costs and foreign talent, MNCs opt to internationalize their R&D activities to benefit from other market externalities, such as shorter times to bring products to market and to tap into localized areas of technological excellence. Reversed flows of FDI can also benefit established innovation centers. MNCs from middle-income economies are increasingly using outward FDI to expand market reach and to capture strategic assets, such as technologies, skills, commercial knowledge and brands. Clearly, local technological competence is only important for attracting FDI of this kind if the prospective subsidiary is going to engage in technology-intensive activities.

Intra- and inter-firm offshoring of R&D increase corporate innovation performance.[29] Key knowledge-generating territories around the world are usually both home to key firms that construct and participate in these international networks and hosts to foreign firms wishing to get access to their knowledge-generating ecosystems, talent pool and researchers.

The existence of a pool of specialized suppliers is also a motivation to connect to another region. A given region may specialize in a certain technology that can benefit complementary industries, even if located in other regions. Bidirectional knowledge flows will be established between the buyer and specialized supplier in the form of technical specifications and goods with embedded technology. In industries with a complex supply chain, these links can involve several hubs, building complex and often international production networks.

Arguably, the forces driving agglomeration successfully attract MNCs and other firms – especially high value-added ones – to particular locations in both developed and developing economies. The resultant clustering makes these destinations progressively less dependent on purely cost-based and relative technological endowment considerations. Intangible location advantages, such as knowledge spillovers, are highly concentrated within specific regions, cities and local systems. The advantages arising from newly vibrant local innovation ecosystems may benefit the MNCs at this location, their headquarters and their entire value chain. The resulting knowledge flows are, therefore, eminently bi- or multidirectional between so-called home and host locations.[30]

Knowledge spread: organization and person-based interactions

Geographical proximity is not the only source of knowledge spillovers today.[31] Knowledge externalities become forces promoting the spread of innovation through organization-level interactions and inter-person or professional-level networks. These organizational and professional connections may be made stronger by geographical proximity, but the latter is not necessary for them to exist.

Long-distance organization-level interactions – for example, interactions within global value chains or across international scientific networks – lower transaction costs within firms and research organizations. These organized structures can facilitate deep knowledge interactions without the requisite of co-location. The effect is enhanced if actors operate within standardized rules or routines set by their organization or pool of organizations. In 1981, Microsoft opened a campus in Silicon Valley just to connect their Seattle operations in Bellevue (and later Redmond) with the effervescence of the Bay Area.

Likewise, more people-based and less institutionalized relations – for example, professional and scientific communities – can also effectively exchange knowledge with a commonly agreed set of rules and routines. This establishes a social proximity – ranging from inter-personal to being part of the same culture or group – among innovators, which lowers interaction costs, eases verification and increases trust to exchange and produce new knowledge.

These economic forces overlap and intertwine to the extreme point of being inseparable. Similar to the forces driving knowledge agglomeration, knowledge-spreading forces are an intrinsic part of the underlying reasoning behind the previously discussed skilled labor- and market-spreading forces.

As seen, the internationalization of corporate R&D plays a key role in all of these long-distance technological interactions, making MNCs one of the most important types of organization and network node in the international spillover of new knowledge. MNCs' international affiliates are gaining more autonomy and becoming – where the right incentives are in place – more embedded in regional and local innovation systems. Increasing autonomy for 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.[32] Characteristics of the regional innovation ecosystem – including its institutions – are particularly important for attracting foreign investment in innovation and technological operations and become relevant factors in attracting investments at more advanced and knowledge-intensive stages of global value chains.

The rise of global innovation networks

Knowledge and innovation production have been international phenomena for a long time, but only recently have they become really global.[33] Nowadays, actors located in different countries can carry out innovation activities in a truly integrated form. Innovation has become increasingly the outcome of global networks connecting dispersed knowledge centers.[34]

It is against this general backdrop of globalization of knowledge and innovation – where their production is done with a higher degree of functional integration – that the concept of global innovation networks has emerged. A global innovation network is a globally organized web of collaboration between organizations – firms and others – engaged in knowledge production that results in innovation. The networks are characterized by (1) their really global spread – and not confined to networks based in high-income countries; (2) their networked nature; and (3) the outcome, i.e., innovation.[35]

Their formation is the result of a knowledge-seeking strategy by the organizations involved, which makes global innovation networks different from global production networks that follow more efficiency- and market-seeking strategies. The focus of global innovation networks is, therefore, knowledge exchange and integration, and subsequent innovation, but not in production or simple manufacturing.[36] Global innovation networks happen largely through the internationalization of corporate R&D.

From this perspective, the MNCs can exert a strong influence on the geographical concentration and global spread – the shape – of global innovation networks by deciding where to locate investment, production and knowledge sourcing.[37] Geographical conditions and the existing sectoral innovation system are particularly important as drivers for the most sophisticated and high value-added stages of supply chains, such as R&D, design or advanced business services.[38] The offshoring of R&D activities has created new interconnected architectures of innovation and research 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 global supply chains in ways that promote economic upgrading and innovation.

At the same time, global participation is a challenge for weaker regions, given the risk of being locked into low value-added and low-innovation activities. The geographic unevenness in participation and embeddedness in global production networks and value chains generates new core–periphery patterns in the global geography of innovation.

Most of the related literature in the field of international business indicates that organization-based linkages – both intra and inter firms – are behind the formation of global innovation networks.[39] International co-inventions – the archetypical indicator for global innovation networks – have expanded greatly to India and China since the 2000s, but a large proportion remains under the control of firms in the U.S., Japan and a few Western European countries. This suggests that companies can and do slice the R&D process in multiple stages/segments – as they do for goods – allowing new countries to participate in the different segments according to their comparative advantage.[40] This facilitates the transformation of existing global value chains or production networks into global innovation networks.

Furthermore, an increasing number of studies suggest personal relationships, aside from organization-based ones, are also critical drivers of the formation of global innovation networks.[41] These relationships range from direct person-to-person innovation-related international collaborations, to the international mobility of scientists, innovators and entrepreneurs.[42] However, organization-based interaction is often the framework where this people-based collaboration can take place. Traditionally, multinationals' internal networks have been a suitable means to partially overcome barriers related to both geographical distance and differing national cultures. But the more recent decline in the costs of travel and communication has certainly favored the rise of person-based international linkages without necessarily an accompanying organizational structure.[43]

1.3 Conclusions

Innovation has always had geographical concentrations or hotspots: Manchester was to the first industrial revolution what San Francisco is to the third. However, for a long period between these two revolutions, it appeared that within the advanced economies the spread of the capacity for innovation was incremental. The strong concentration of innovation since the end of the 20th century thus requires additional consideration.

Firms used to cluster along supply chains. In the first and second industrial revolutions, innovation activity clustered together with leading production activities, making for large industrial cities, some of which also concentrated R&D and product development. Over the last century, these patterns of agglomeration have slowly changed. Location choices have become more determined by shared skill requirements – especially in the services sector – such as labor market pooling across different but related innovation sectors.[44] 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 a result, leading urban agglomerations of innovation today specialize in the abstract, cognitive and conceptual tasks of R&D and innovation. These highly specialized sectors and complementary broad service sectors have displaced the traditionally co-located routine production tasks observed in the past.[45]

The consequences of this new concentration of innovative activity are far reaching. Ultimately, the geographical distribution of innovation shapes the economic development path of cities and broader regions. One prominent feature of the geography of economic development in recent times is the inter-regional divergence of incomes within countries (see Chapter 5). Generally speaking, large metropolitan areas – the hotbeds of agglomerated ecosystems of innovation – are increasingly outpacing other regions in terms of income growth.

Yet, there is also divergence within these large metropolitan areas. Jobs in innovation-related activities tend to pay higher wages than others. Rapid growth in a concentrated geographical 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, inflows of high-earners, combined with limited housing supply, often result in growing inequality and falling disposable income for low-earning households.[46] Ultimately, this may lead to increased sorting by skill groups into innovative, high-earning areas and non-innovative, low-earning areas, excluding the low-skilled from the opportunities and amenities of living and working in an innovative environment.[47]

These patterns seem to prevail in the largest global innovation hotspots around the world. They are the primary homes and hosts of major knowledge-based multinational corporations and the true beneficiaries of globalization, being centers of corporate decision-making and control, knowledge generation and exchange, skills and jobs. But their prosperity is accompanied by high levels of income inequality and spatial segregation, leading some to speak of a new "urban crisis."[48]

There is still limited evidence on which to draw firm conclusions as to the causes and consequences of the concentration and spread of innovative activity. This may partially reflect the complex nature of innovation processes and their uncertain impact. However, the long-term consequences deserve careful consideration, even with partial knowledge.

Notes

1 This chapter draws on Crescenzi *et al*. (2019b).
2 Acemoglu *et al*. (2005), Mokyr (2005) and WIPO (2015).
3 Crafts and Venables (2003).
4 Storper (2018).
5 Glaeser and Maré (2001).
6 Crescenzi *et al*. (2007).
7 Kemeny and Storper (2019).
8 Scott and Storper (1987).
9 Crescenzi *et al*. (2019b).
10 Krugman (1991).
11 Boschma and Frenken (2006).
12 These three externalities are referred to as Marshallian externalities (Krugman, 1991).
13 Boschma and Frenken (2006).
14 Lécuyer (2006).
15 These are known as Jacobsian externalities (Jacobs, 1961).
16 Frenken *et al*. (2007).
17 Chatterji *et al*. (2013).
18 Mazzucato (2015).
19 Hardin (2008).
20 See, e.g., Hershberg *et al*. (2007).
21 Crescenzi *et al*. (2019b).
22 Davis and Dingel (2019) and Feldman *et al*. (2005).
23 Bathelt *et al*. (2004), Boschma (2005) and Frenken *et al*. (2007).
24 WIPO (2017).
25 Archibugi and Iammarino (2002).
26 Crescenzi *et al*. (2019b).
27 Breschi *et al*. (2017)
28 Branstetter *et al*. (2014). See also Chapter 2.
29 Nieto and Rodríguez (2011).
30 Iammarino and McCann (2018).
31 Boschma (2005).
32 Cantwell (1995).
33 Chaminade *et al*. (2016).
34 Cano-Kollmann *et al*. (2016).
35 Barnard and Chaminade (2011).
36 Chaminade *et al*. (2016)
37 Crescenzi *et al*. (2019a).
38 Alcácer and Chung (2007) and Chidlow *et al*. (2009).
39 Bathelt *et al*. (2004).
40 Branstetter *et al*. (2014).
41 Lorenzen and Mudambi (2013).
42 Breschi *et al*. (2017) and Saxenian (1994, 1999).
43 Cano-Kollman *et al*. (2016).
44 Diodato *et al*. (2018).
45 Crescenzi and Iammarino (2017) and Duranton and Puga (2005).
46 Moretti (2012).
47 Diamond (2016).
48 Florida (2017) and Rodriguez-Pose (2018).

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The top 10 collaborative hotspots of the world account for 26% of all international co-inventions.