The geography of innovation can seem paradoxical: the generation of scientific knowledge and innovation is both increasingly global and intensely concentrated in a few local hotspots.

New players, particularly Asian countries, are responsible for more and more scientific research and inventions, which were once the almost exclusive domain of a handful of rich economies. At the same time, this greater international spread has been accompanied – at country level – by increased concentration of innovative activity within a few densely populated areas. These urban areas are vibrant innovation ecosystems, such as Silicon Valley outside San Francisco in the U.S or China's Shenzhen–Hong Kong, a more recent hotspot.

This paradox is more apparent than real, however; the world's most innovative urban agglomerations are also the most open to the outside world. Sometimes, they are better connected internationally than they are to their national hinterlands. Together, they form what economists have come to refer to as global innovation networks. Skilled individuals and innovative companies are at the center of these networks. Highly skilled workers gravitate toward innovative urban areas because they want to interact with one another and enjoy the amenities of metropolitan life. Large cities offer companies a large local market, specialized suppliers and academic institutions that allow them to reap economies of scale and scope. Knowledge, in turn, flows more fluidly among company and university researchers when they work in close proximity, fueling the innovation engine.

This WIPO report analyses these dual trends, exploiting a rich data set of millions of patent applications and scientific publications. Its findings argue for increasing openness and support for collaboration if innovation is to continue to flourish.

Knowledge creation is spreading to more and more countries

For most of the period from 1970 to 2000 only three countries – the United States of America (U.S.), Japan and Germany – accounted for two thirds of all patenting activity worldwide. When the remaining Western European economies are included the share reached some 90 percent. But in the years since, the rest of the world has come from almost nowhere to account for almost one third of all patenting activity. Published scientific data have spread even more widely, with the rest of the world going from less than a quarter of all such publication to around half over the last 20 years.

China and the Republic of Korea are largely responsible for the rising share of new areas in knowledge production and innovation; together, they account for over 20 percent of patents registered in the years 2015–2017, compared to under 3 percent in 1990–1999. Other countries, notably Australia, Canada, India and Israel, have also contributed to the global spread of innovation. Many middle-income countries, however, and all lower-income countries, continue to have substantially lower levels of patenting activity.

The increasingly dispersed and interconnected flow of knowledge and innovation has mirrored the development of complex global networks, or value chains, for the production and delivery of goods and services. In particular, multinational companies have located knowledge-intensive production stages – most importantly research and development (R&D) – in urban agglomerations that offer specialized knowledge and skills. More generally, it is the need for greater collaboration in the face of growing technological complexity that has driven both the increasing concentration of innovation in certain urban areas and its global spread.

Innovation is increasingly local

On the basis of geocoded inventor and scientific author data, this report explores the geography of innovation within countries and identifies the world's main agglomerations of scientific and technological activity. It looks at two types: global innovation hotspots, which show the highest density of scientific publication or patent activity; and specialized niche clusters, where the density of inventors and scientific authors is high in a given field but not high enough generally to be a global hotspot.

Innovation is geographically concentrated in a limited number of areas

The emerging landscape of global hotspots and niche clusters shows that inventive and scientific activity within each country is persistently concentrated in a few large, cosmopolitan and prosperous urban areas. In the U.S., hotspots around New York, San Francisco and Boston accumulated roughly a quarter of all U.S. patents filed from 2011 to 2015. In China, those around Beijing, Shanghai and Shenzhen increased their share from 36 percent to 52 percent of all Chinese patents during the same period.

Less than 19 percent of all inventive and scientific output worldwide is generated by inventors or researchers located outside hotspots and niche clusters. Despite this big change in the global innovation picture, more than 160 countries – the vast majority – still generate little innovation activity and do not host any hotspot or niche cluster.

Big cities are not necessarily hubs of innovation

Not all large metropolitan areas are innovation dense. For example, North America hosts most hotspots in dense urban areas along the east and west coasts, while many dense inland urban areas do not have an equivalent density of innovation. Asia, Latin America and Africa host many dense urban areas with no corresponding innovation density. Despite high populations, top metropoles – for example, Bangkok, Cairo, Cape Town, Kuala Lumpur and Santiago de Chile – only have a modest degree of innovation density in some specialized fields.

And less dense urban areas can sometimes host niche clusters. Some examples are Ithaca in the U.S., Stavanger in Norway and Bern in Switzerland, which are highly innovative cities due to the strong innovation footprint of local academic institutions, industries or, sometimes, the presence of a key company.

Collaboration is increasingly the norm

Data show that teams are involved in an increasing majority of scientific papers and patents. In the early 2000s, teams already produced 64 percent of all scientific papers and 54 percent of all patents. By the second half of the 2010s, these figures had grown to almost 80 percent and 70 percent, respectively.

Most high-income economies also show rising international collaboration. The forces pushing academia and companies to cross borders seeking partners for innovation are manifold. The scientific community has a long tradition of engaging in international collaboration, while multinational companies seek efficiency gains from the international division of their R&D and through international collaboration.

The main exceptions to the trend toward internationalization are East Asia's top economies where Japan, the Republic of Korea and, more recently, China have seen falling shares of international collaboration, though not in absolute number terms.

A few countries account for most of the international ties

Most international collaboration is concentrated among a few main countries. In the period from 2011 to 2015, the U.S. and Western Europe accounted for 68 and 62 percent, respectively, of all international inventive and scientific collaboration. Most of the collaboration happens among inventors and researchers from these countries. New entrants to these collaboration networks, from countries such as China, India, Australia and Brazil, still mostly collaborate with the aforementioned economies rather than with each other.

Hotspots and clusters drive international collaboration and global networks

Most global innovation hotspots have increased their international collaboration over the last two decades. This collaboration – whether national or international, patents or publication – forms a thick web of ties that constitutes the global innovation networks. The shape of these networks has evolved, typically with more nodes and ties being added over time.

Inventors and scientists within hotspots and niche clusters collaborate internationally more than those outside, particularly in scientific articles. Over the last two decades, the share of scientific publication involving international collaboration between scientists from inside hotspots has been more than triple that between scientists outside of them.

Collaboration is concentrated

Notwithstanding new network nodes and their ties, the hotspots in the U.S., Europe and Asia remain the core of the global networks both in terms of output and connectivity. Overall, larger hotspots collaborate both nationally and internationally, whereas niche clusters and smaller hotspots collaborate predominantly at the national level. For instance, many French and United Kingdom (U.K.) hotspots connect with the rest of the world mostly through Paris and London respectively. In China, Shanghai, Beijing and Shenzhen act as the top gatekeepers.

Yet, not all hotspots have the same relevance in terms of connections. U.S. hotspots are among the most connected nodes. Beijing, London, Paris, Seoul, Shanghai and Tokyo are also highly connected, but much less so. Interestingly, the high volume of inventive and scientific activity of the U.S. hotspots does not fully explain their higher connectivity. Many other hotspots – for example, Tokyo or Seoul – show larger

or similar scientific or inventive output but are not so highly connected.

The intensity of international collaboration varies considerably across countries. For example, hotspots in India and Switzerland are highly connected internationally, while those in the Republic of Korea and Japan are weakly connected. In many hotspots, internationalization often goes hand-in-hand with an increase in the share of local-only interactions. In many Chinese hotspots the number of co-inventions within hotspots has grown remarkably, leading to a decline in share of both national and international collaboration outside these hotspots.

Multinational companies lie at the center of the web

Patent data shed light on the corporate R&D networks at the center of global innovation networks. Multinational companies from around the world increasingly list foreign inventors in their patent applications and those foreign inventors come from a widening set of countries. In the 1970s and 1980s, only 9 percent of patents filed by U.S. companies had foreign inventors; by the 2010s, this share had risen to 38 percent. Western European companies saw a similarly sharp increase, from 9 percent to 27 percent in the same period.

Such international patent sourcing still mostly happens between companies and inventors from high-income economies. In the 1970s and 1980s, 86 percent of the international patent sourcing was between multinational companies and inventors from the U.S., Japan and Western European countries. However, this share fell to 56 percent in the 2010s.

Middle-income economies are new players in MNC networks

Two main developments explain this fall. On the one hand, multinationals from these countries increasingly outsourced R&D activities to middle-income economies, particularly China, India and, to a lesser extent, Eastern Europe. For instance, in the 2010s, more than a quarter of all international patent sourcing by U.S. multinational companies had an inventor from China or India. On the other hand, multinationals from middle-income economies also actively participate in global innovation networks. Companies from Asia, Eastern Europe, Latin America and Africa rely intensively on the ingenuity of U.S., Western European and Chinese inventors.

Innovation hubs move and can disperse over time

Multinationals can have very different needs and strategies as to where to source for talent, and these can change over time. For example, Google and Siemens have concentrated inventive activities within their top hubs. In the 2010s, San Jose–San Francisco accounted for 54 percent of Google's patents, up from 36 percent in the 2000s. Similarly, Nuremberg – the most important source of patents for German manufacturing company Siemens – accounted for 32 percent during the 2010s against 27 percent in the 2000s.

The concentration is even greater in Asian companies, though it has slightly decreased over time. Tokyo and Shenzhen–Hong Kong were the most important inventive sources for Sony and Huawei in the 2010s, accounting for 71 percent and 81 percent of patents, respectively. However, this is down from a respective 83 percent and 88 percent in the previous decade, suggesting a relative dispersion of innovation.

Innovation is reshaping the car industry

The report delves deeper into the evolving geography of innovation by studying two industries seeing profound change. One is the automotive sector, which is in the early phases of technological disruption. New entrants – from within the automotive industry and from the information technology (IT) industry – are challenging established players.

Fully autonomous vehicles (AV) have yet to reach the market. Nevertheless, artificial intelligence (AI) data analytics and the interconnectivity of devices and components are reformulating the industry's business model toward services and the so-called "platform economy." Traditional automakers fear being displaced in their core business of making and marketing cars.

Patent data suggest that traditional automakers and their suppliers are at the forefront of AV innovation. Ford, Toyota and Bosch – accounting for 357, 320 and 277 of AV patent families, respectively – are the top three AV patent applicants. However, non-automakers also

feature in the list of top patent applicants. Google, and its AV subsidiary Waymo, are in eighth position with 156 patents, ahead of traditional automakers like Nissan, BMW and Hyundai. Uber and Delphi each have 62 AV patents and are ranked joint 31st.

Incumbents and new entrants collaborate among and between themselves

Neither the incumbents nor the new entrants currently have all the required competencies for producing AVs. They either need to join forces or else develop internally the respective skills they lack. AV innovation is a long-term and costly endeavor. Stakeholders have high incentives to collaborate and share risks and costs with different type of partners. Three types of collaboration are forming: between incumbent automakers; between tech firms, and between automakers and tech firms. The emerging collaboration network is an amalgam of all the above: none is mutually exclusive, and they coexist.

Automotive and IT firms stay tied to their traditional clusters

The top automakers and top IT giants still strongly favor home-based sites for their inventive activities. There is some shift in geography at the margins, so it might be too early to give a definitive answer as to whether AV technology will change the geography of innovation in the automotive industry.

Innovation is sown in biotech labs and harvested in agricultural clusters

Crop biotechnology is an industry where innovation has to be adapted to local agro-ecological conditions. While most plant biotechnology inventions may come from high-income countries – for example, the U.S., Western Europe and East Asian countries – they still need adapting to different climate and soil conditions. Most of the transgenic crops used in emerging middle-income countries during the late 1990s were locally adapted germplasms of their North American counterparts. As a result, plant biotechnology innovation clusters exist in many parts of the world. However, the data show that crop biotechnology innovation in many countries in Africa, Latin America and the Caribbean, and Asia is geographically concentrated.

The landscape of plant biotech innovation

A handful of countries accounts for the bulk of biotechnology inventive and scientific output. The U.S., Germany, China, Japan and the Republic of Korea accumulate more than 55 percent and 80 percent of all crop biotechnology articles and patents, respectively. Only Argentina, Australia, India, Israel, Mexico and Singapore join them in the list of countries hosting plant biotechnology clusters; and, except for Australia, they all have only one.

There is a geographic divide between where plant biotech innovation occurs and where transgenic crops are farmed. In most cases, crop biotechnology hotspots are located in large metropolitan areas, either in global innovation hotspots or in specialized niche clusters with strong biotech competences. This also holds for developing countries, where national crop biotechnology clusters are typically located in large urban areas, such as São Paulo in Brazil and Cape Town.

Some clusters are close to rural areas – for example, Viçosa in Brazil or Irapuato in Mexico. Wherever they are, their presence is usually associated with influential public institutions, such as universities, international agricultural research centers and/or national agriculture research systems.

Increasing private–public collaboration

Private firms, particularly the four major agrobusiness companies – Bayer and BASF from Germany, ChemChina and Corteva Agriscience from the U.S. – undertake a large part of the R&D investment in plant biotechnology. The need for access to proprietary technologies has spurred collaboration within the industry through cross-licensing, licensing-in, joint research ventures and even mergers and acquisitions.

Nevertheless, there is an increasing need for collaboration with the public sector to access, for example, pools of germplasms and cultivars – crop varieties with desirable traits – often held by public research institutions. For public institutions the high costs of commercializing crop biotechnology products almost always require collaboration with large multinational companies. Since the 2000s, co-patenting between private firms and public institutions has overtaken co-patenting among private firms to become the main type of collaboration. In fact, since the 2010s, co-patenting between

private firms has slipped to third in importance behind co-patenting between public institutions.

Openness in pursuit of innovation brings mutual gains

What does the global geography of innovation, as portrayed in this report, imply for policymaking? The growth of global innovation networks has relied on policies favoring openness and international cooperation, but this should not be taken for granted – especially as public perceptions have become more skeptical of the benefits of globalization.

Economic theory offers good reasons why the free exchange of knowledge is beneficial: it promotes the specialization of different innovation clusters around the world, leading to more efficient and diverse knowledge production. The public good nature of knowledge reinforces the benefits of openness: if knowledge flows generate economic benefits abroad without diminishing those at home, there are bound to be mutual gains from openness.

Theoretically, there may well be circumstances in which strategic restrictions on trade and knowledge flows could benefit the growth paths of economies. However, the experience of high-income economies over the past decades suggests an overall positive impact from the flow of knowledge about new technologies.

Falling R&D productivity reinforces the case for openness

Continuously pushing the technological frontier is becoming exceedingly difficult. Evidence suggests that achieving the same level of technological progress as in the past requires more and more R&D effort.

Falling R&D productivity calls for constantly increasing investments in innovation. It also calls for collaboration and openness. Finding solutions to increasingly complex technological problems requires larger teams of researchers and greater specialization in research, both of which can be promoted by openness and international collaboration.

Making openness work requires international cooperation…

International cooperation in relation to innovation has many dimensions. It is needed to promote incentives for investments in innovation that reflect the demands and size of the global economy. It can also play an important role in making it easier for innovators to do business internationally. Lastly, governments can pool resources and fund large-scale scientific projects that exceed national budgets or require technical knowledge available in different countries.

…and policies that address growing regional divergence

One worrying trend of the past few decades is the increasing inter-regional polarization of incomes, innovative activity and high-skilled employment and wages within countries. Openness strengthens the gravitational pull toward champion regions. As this report demonstrates, the most vibrant innovation hotspots, which are embedded in global innovation networks, tend to be located in what are already the richest metropolitan agglomerations within countries.

Regional support and development policies can play an important role in helping regions that have fallen behind. While not reversing the gravitational pull of successful regions, they can promote innovation-driven growth that benefits economies as a whole.

Innovation is increasingly concentrated in urban "hotspots." At the same time, these hotspots are connecting and collaborating across the world.