Chapter 5

Policy perspectives: the case for openness

Innovation has always spanned countries and continents. At the turn of the 20th century, the Wright brothers in the United States of America (U.S.) and Alberto Santos-Dumont in Brazil invented the first airplanes to fly successfully. Yet, the development of the modern airplane owes much to scientific advances in Europe that explained why heavier-than-air machines could fly.[1] The development and dissemination of the agricultural technologies that unleashed the green revolution after the Second World War relied on partnerships between the Ford and Rockefeller Foundations in the U.S. and a large number of agricultural research institutes in developing economies.[2] Tim Berners-Lee invented the World Wide Web at the European Organization for Nuclear Research (CERN) – a research consortium on the Franco–Swiss border sponsored by 23 (mostly) European countries.[3]

As documented in this report, innovation today is both highly localized and international at the same time. Different agglomeration forces have favored the formation of innovation hotspots that typically fall within large metropolitan regions. A limited set of hotspots lead the way and are at the center of global innovation networks. Various formal and informal links connect the nodes of these networks, with multinational companies playing a key role within them. Evidence from patent and scientific publication records suggests that the cross-border dimension of these links has increased over the past decades.

The growing internationalization of innovation owes much to technology itself. Advances in information and communication technologies (ICTs), in particular, have fueled the flow of knowledge over long distances. Crucially, however, the growth of global innovation networks has relied on policies favoring openness and international cooperation. Such an environment of openness and cooperation should not be taken for granted – especially, as public perceptions have become more skeptical as to the benefits of globalization in general in recent years.

This closing chapter therefore reviews the case for openness in the pursuit of innovation. It does so primarily from an economic perspective. At times, whether and how to partner with foreign innovators involves questions of national security, which go beyond the scope of the chapter's discussion.

5.1 The economics of openness

Openness of national innovation systems entails the free exchange of knowledge between economies. Knowledge may flow across borders when researchers communicate with each other, or when they read scientific journals and patent documents published abroad. It may also occur through international trade, when knowledge is embedded in goods and services; and it may occur through migration, when it is embedded in people.

How do restrictions on the international flow of knowledge affect national economies and the world as a whole? The answer depends crucially on which knowledge flows the restrictions target, the capabilities of national innovation systems, patterns of production and employment, and the nature of the economic growth process. While not offering a definite conclusion, the economic literature offers some guidance on the effects of knowledge flow restrictions, which this section strives to summarize.

Gains from specialization

One simplified way to approach the question is to view knowledge like any other good. Just as the production of cars requires capital and labor inputs, so does the production of new knowledge through innovation.

Restricting international knowledge flows then affects how economies allocate resources toward different production activities. Viewed this way, the traditional predictions of international trade theory apply. Above all, openness leads to production and trade patterns that allow economies to specialize based on their comparative advantage. Trade economists usually consider two forces that give rise to specialization:[4]

- *Differences in factor endowments*. An economy richly endowed with capital will specialize in and export goods that are capital-intensive to produce. Conversely, an economy richly endowed with labor will specialize in and export goods that are labor-intensive to produce.
- *Differentiated varieties and economies of scale*. Where goods come in differentiated varieties – say, different car brands – and production of those varieties entails economies of scale, economies will specialize in and export some varieties and import others.

These predictions can shed light on important facets of the global geography of innovation. Innovation requires highly skilled labor, which explains why most innovative activity takes place in high-income countries where such labor is relatively abundant. At the same time, the decision by multinational companies to locate some research and development (R&D) activities in certain developing economies, such as China and India, reflects the availability of highly skilled labor at lower wages – fully in line with patterns of comparative advantage.[5]

The notion of differentiated varieties, in turn, finds its equivalence in the specialization of different innovation clusters around the world. For example, there are many innovation clusters focusing on medical technology, with each offering specialized knowledge not available elsewhere. This generates bidirectional knowledge flows, even among otherwise similar economies. Global innovation networks act as a broker for such knowledge flows.

Trade theory holds that there are mutual gains from comparative advantage-based trade. These gains take the form of increased economic efficiency and a wider variety of goods available to businesses and end-consumers. Given the highly specialized nature of innovative output, the variety effect seems particularly important to knowledge trade.

Notwithstanding these mutual gains, trade theory also holds that open trade affects the distribution of incomes within economies. Such distributional effects are stronger if differences in capital and labor endowments give rise to international trade. In other words, they are more important for trade between dissimilar economies – notably between economies at different levels of development. As will be further discussed below, these distributional effects matter for policy.

Innovation as a global public good

Viewing knowledge like any other good helps explain important aspects of the global innovation landscape. However, it is a highly simplified view that fails to account for the unique characteristics of knowledge production and knowledge consumption.

Above all, knowledge has attributes of what economists refer to as a public good: many people can use it at the same time, without diminishing the use of the knowledge by those who produce it.[6] For example, the basic science behind artificial intelligence emerged from a limited number of scientific organizations, yet a large number of innovations employ this science for a wide variety of applications around the world.[7]

In practice, there are limits to how widely knowledge can be shared. In fact, a central tenet of economic geography research is that knowledge does not flow freely within and across economies; knowledge flows have distinctive geographical patterns and biases.[8] One reason is that absorbing and applying cutting-edge knowledge often requires highly specialized skills that are in scarce supply.[9] Moreover, for some forms of knowledge to flow, human interaction is required, which is precisely a key reason for innovative activity to agglomerate (see Chapter 1).[10]

Yet, to the extent that knowledge lives up to its public good potential, does this change the case for openness? In fact, it strengthens it. If knowledge outflows generate economic benefits abroad without diminishing the use of knowledge at home, there are bound to be mutual gains from openness.

Innovation and growth

Innovation differs in another important way from other goods produced in the economy. Through innovation, companies can create a competitive edge over their rivals. A successful innovator can gain market share at the expense of a company that fails to be cutting-edge. Competition based on innovation, in turn, drives productivity enhancements and long-term economic growth.

As companies compete on the global stage, commentators have applied the same logic to economies as a whole. Accordingly, those economies that are successful at innovating grow faster at the expense of economies that do not innovate successfully.[11] In such a zero-sum world, restricting knowledge outflows would help economies retain an innovative edge and avoid "falling behind" other successfully innovating economies.

At the outset, the international economics literature would dismiss such "simplistic" zero-sum scenarios. Economies as a whole differ from companies in important ways. For one, economies as a whole cannot go bankrupt. If companies in a particular sector exit the market or lose market share due to foreign competition, they free up labor and capital that can be deployed elsewhere in the economy.

The reverse happens in sectors gaining international market share – they attract labor and capital from elsewhere in the economy. In addition, faster productivity growth in successfully innovating economies enlarges their size and increases demand for foreign products.

Overall, innovation leads to adjustments in prices, wages and exchange rates, which prompt shifts in production and trade patterns. Clearly, economies that are successful at innovating will, in the long term, experience faster overall economic growth than those that fail to do so. However, this does not necessarily mean that one economy's success constrains another economy from being equally successful. In fact, the public good nature of knowledge suggests that innovation can contribute to productivity growth everywhere.

Notwithstanding this general optimism, as national innovation performance shapes patterns of production and trade, it is conceivable for one economy to end up specializing in activities that put it on a permanently faster or slower growth path. Strategically restricting trade and knowledge flows could then tilt production patterns in such a way as to favor faster growth at home. Box 5.1 summarizes theoretical research that identifies the conditions in which such "zero-sum" outcomes can arise.

Whether such conditions prevail in practice is ultimately an empirical question. Rigorously answering it is not easy, given that one does not know how different economies would fare under different trade and knowledge-flow policies. However, one can look at the actual growth experience of economies around the world over the past decades. One important pattern is that today's high-income economies have experienced remarkably similar growth over the past 40 years. Before 1980, per capita incomes of poorer high-income economies saw faster growth than those of richer high-income economies. But this convergence process eventually slowed (Figure 5.1). While differences in per capita incomes persist, the most advanced economies have grown largely at a similar pace since the 1990s (Figure 5.2). This may suggest that new technologies have spread seamlessly across the set of economies already at the technology frontier and they have stimulated growth in comparable magnitudes.

Beyond the group of high-income economies, the growth experience has been mixed. For a long time, incomes across the world diverged.[12] In 1870, the gross domestic product (GDP) per capita of the richest economy was around 10 times that of the poorest one; by 2008 this gap had widened to a factor of 126.[13] For a very long time, poorer economies did not grow any faster than richer ones. More recent data – starting from the 1990s – suggest a reversal of this trend, with incomes converging across economies. In other words, since the 1990s, poorer economies have, on average, grown faster than richer ones.[14]

Box 5.1 Theoretical foundations of strategic trade policy

A branch of trade theory in the 1980s and early 1990s was devoted to analyzing the circumstances in which departures from free-trade policies may be welfare enhancing. Many underlying models focused on imperfectly competitive markets and trade policies that might increase the share of excess economic profits flowing to the domestic economies.[15] Some more complex theories also accounted for the role of innovation in driving long-term growth. The book by Gene Grossman and Elhanan Helpman (1991) provides the most detailed treatment of these latter theories.

In relevant models, firms invest in R&D with the prospect of reaping economic rents in imperfectly competitive product markets. Competitive market forces, in turn, sustain incentives to continuously invest in R&D, thereby generating the productivity gains that sustain growth in the long run. Mindful that companies compete in a global arena, the models then analyze the interdependence of growth processes in different countries.

The predictions stemming from these models confirm, first of all, the general optimism expressed in the text: global interactions generate forces that accelerate growth in every country. But they also point to reasons why this may not always be the case. For example:

- Suppose that an economy has a comparative disadvantage in research due to limited high-skilled labor. Integration with the rest of the world could then lead it to specialize in more stagnant activities, with overall output growing more slowly.
- Suppose that knowledge does not easily flow across borders, because it is difficult to reverse engineer or it requires critical skills not available in recipient countries, as described in the text. Integration may then lead economies that are small in size – or that historically have conducted little research – to specialize in manufacturing activities, preventing the onset of innovative activity. In fact, small differences in initial conditions between economies can lead to perpetual differences in productivity growth.

In the presence of such forces, strategic trade and related policies could well reshape patterns of production and alter an economy's growth path. In practice, successfully implementing such policies is difficult. The choice of policy instruments depends critically on initial conditions, the evolving nature of competition and technological opportunities. Given that the future path of technology and its implications for markets are highly uncertain, choosing the right policy mix in a forward-looking way is a formidable challenge.

Notwithstanding this trend reversal, average convergence does not mean universal or automatic convergence. Some poorer economies have been more successful at catching up to the richer ones than others. Developing countries in East Asia and, more recently, India, have been particularly successful at doing so. Given their central role in the growth process, knowledge flows and innovation must be part of the explanation behind these trends. However, which precise structural forces and economic policies have favored catch-up growth remains the subject of considerable debate.[16] A pessimistic view is that the historical concentration of innovative activities in a limited set of economies and the strong agglomeration forces associated with such activities reinforce a global core–periphery division. Even if policies do not restrict knowledge flows, this division fosters diverging development paths. A more optimistic view is that innovation eventually spreads beyond the core group of innovators; with the right policies, economies in the periphery can absorb foreign knowledge and catch up.

In conclusion, the economic literature offers good reasons why openness is bound to be beneficial in the pursuit of innovation. Theoretically, there may well be circumstances in which strategic restrictions on trade and knowledge flows could alter the growth paths of economies. However, it is difficult to translate this theoretical possibility into concrete policy proposals. As pointed out in Box 5.1, adopting the right policy instruments in a forward-looking way is a formidable challenge. Practically, it may be difficult to prevent knowledge from flowing abroad, without at the same time restricting knowledge circulating within economies. In addition, one economy's policy choices may prompt policy responses from other economies.

High-income economies grow at a similar pace

Figure 5.1 Gini coefficient, real GDP per capita, group of high-income economies

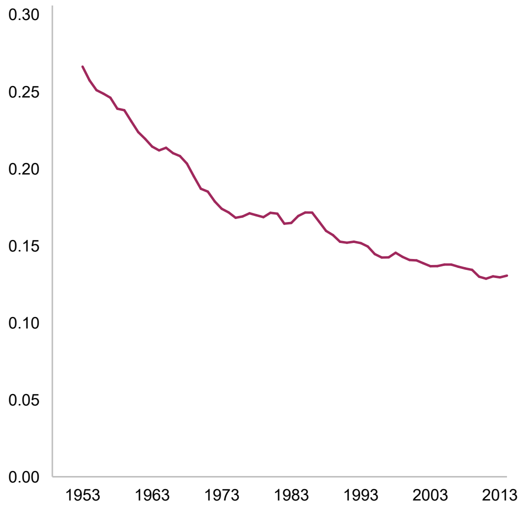
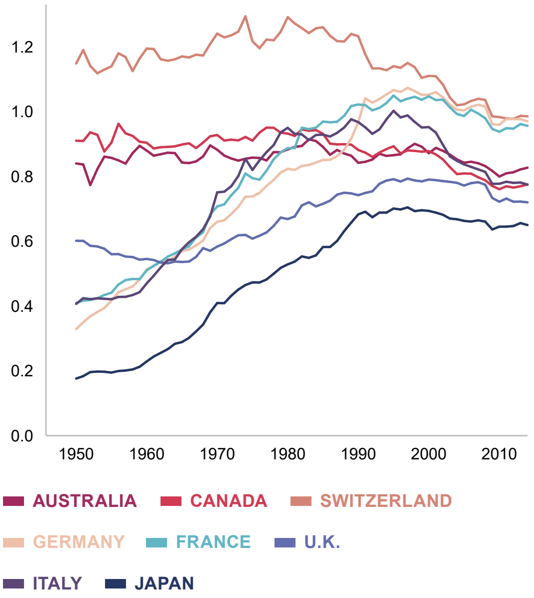


Figure 5.2 Real GDP per hour worked, relative to U.S.



Note: The Gini coefficient measures the distribution of incomes on a scale of 0 to 1; the lower the value, the greater the equality. GDP per capita ratios in figure 5.2 are based on constant 2011 U.S. dollar real GDP figures, with 1.0 representing parity with the U.S. Values greater than 1.0 mean that a country's GDP per hour worked exceeds that of the U.S. The group of high-income countries includes Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Israel, Italy, Japan, Netherlands, New Zealand, Norway, Republic of Korea, Spain, Sweden, Switzerland, U.K., U.S.
Source: Penn World Table, version 9.0, available at www.ggdc.net/pwt

Such policy reciprocity may well undermine the case for strategically limiting openness. Finally, the growth experience of high-income economies over the past decades suggests an overall positive-sum impact of new technologies.

5.2 Openness in an age of falling R&D productivity

The case for openness becomes even stronger when considering the context in which innovation takes place today. 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. For example, Gordon Moore – the co-founder of Intel – famously predicted in 1975 that the number of transistors on a computer chip would double every two years. What came to be known as Moore's Law has roughly held up until today. Notably however, to double chip density today requires 18 times more researchers than it did in the early 1970s.[17]

Other fields of technology show similar signs of slowing R&D productivity: it takes multiple times as much medical R&D to achieve similar increases in life expectancy as in the past; investments in agricultural R&D have grown more rapidly than increases in agricultural crop yields.[18] More generally, most high-income economies have seen a gradual decline in the growth of economic productivity over the last half century. Economist Robert Gordon has prominently attributed this decline to innovations of the recent past boosting productivity growth by less than innovations of the more distant past.[19] In particular, he argues that the innovations associated with the second industrial revolution supported fast productivity growth in high-income economies until the 1970s; the innovations associated with the third (digital) industrial revolution have not been able to sustain such fast productivity growth.

Policies cannot alter opportunities for technological progress. However, policies shape to what extent those opportunities are realized. They determine how much resources are invested in R&D, how R&D is performed and how innovations find their way into the economy. Falling R&D productivity calls for constantly increasing investments in innovation – both scientific research and applied R&D. It also calls for collaboration and openness. Finding solutions to increasingly complex technological problems requires larger teams of researchers (see Chapter 2) and greater specialization in research. Openness and international collaboration promote such specialization and can thus help slow declining R&D productivity.

For openness to work, policymakers need to go beyond simply dismantling border barriers. There is an important role for international cooperation to support openness. Equally important, policymakers need to address regional imbalances that openness may partly foster. The final part of this chapter looks at these two critical dimensions.

Fostering international cooperation

International cooperation in relation to innovation has many dimensions. An important one is to promote incentives for innovation investments that reflect the demands and size of the global economy. Setting international rules for the protection of intellectual property (IP) rights serves this purpose. In practice, international treaties on IP typically establish the principle of nondiscrimination, namely that national laws treat domestic and foreign IP owners equally. They also set certain standards for the protection of different types of IP – for example, which inventions should be eligible for patent protection or how long copyright should last. At the same time, these standards do not fully harmonize IP protection across the world and leave room for national policies to tailor IP protection to national needs.

A second important dimension is to promote the ease of doing business internationally. Innovating companies and knowledge workers face a variety of regulatory measures when operating in markets around the world. Promoting the compatibility of national regulatory systems can help reduce the costs of regulatory compliance. For instance, some level of recognition of foreign regulatory standards can reduce the wasteful duplication of product testing and associated paperwork, without necessarily compromising regulatory objectives. Recognition of foreign qualifications in line with domestic standards can help facilitate the international mobility of knowledge workers. Regular dialogues between national regulatory agencies underpin such recognition frameworks. Similarly, setting technical standards at the international level can avoid the costly adaptation of products to different markets. In the area of IP, WIPO's international filing treaties – in particular, the Patent Cooperation Treaty, the Madrid System and the Hague System – facilitate the acquisition of IP rights in many countries by filing a single international application; the ultimate grant of IP rights remains a national decision.

Finally, governments can pool resources and fund large-scale scientific projects that go beyond the envelopes of national budgets or require technical knowledge available in different countries. CERN – mentioned at the outset of this chapter – is a good example of such cooperation. The International Space Station is another one. It is a joint project between the national space agencies of Canada, Japan, the Russian Federation and the U.S., as well as the European Space Agency. Launched in 1998, it has hosted more than 200 visitors from 18 different countries.[20]

Addressing regional imbalances

As discussed in Chapter 1, one worrying trend of the past few decades is the increasing inter-regional polarization of incomes, innovative activity, high-skilled employment and wages within countries. Up to the 1980s, most high-income economies saw a steady convergence of incomes across regions.[21] Poor regions of countries caught up with rich ones. Since then, inter-regional convergence has slowed and, in some cases, it has even reversed. In the U.S., the convergence process slowed markedly starting in the 1990s.[22] European economies have similarly seen slowing regional convergence and, since the onset of the great recession in 2008, outright divergence. A few "champion" regions within European economies with already high levels of income have seen substantially faster growth than many of the poorer regions.[23]

There are many reasons for the polarization of economic activities within countries. The declining importance of agriculture and mining activities in economic output has long favored a gravitational pull toward big cities. In a knowledge-based and services-dominated economy, businesses have strong incentives to locate within large metropolitan areas. Openness arguably strengthens the gravitational pull toward champion regions. The most vibrant innovation hotspots, which are embedded in global innovation networks, tend to be located in what already are the richest metropolitan agglomerations within countries. Their international success reinforces their domestic lead. As described in Chapter 1, successful innovation agglomerations may also see diverging incomes within them, with fast growth of high-skilled jobs placing pressure on disposable income in low-skilled occupations. Israel offers a good example of how burgeoning innovation activities have raised concerns about a dual track economy (see Box 5.2).

Addressing such rising regional imbalances is one of the most difficult challenges for policymakers. Trying to reverse the gravitational pull of successful regions may be neither feasible nor desirable. Restricting participation in global innovation networks, in particular, would undercut an economy's ability to generate cutting-edge innovations. In any case, openness is but one contributing factor to regional imbalances.[24] The long-term structural transformation of economic activity is arguably the fundamental driving force behind such imbalances. Internal migration from lagging to thriving regions only offers a partial solution to regional divergence. Individuals may not have the capacity or willingness to move. High housing prices in thriving regions alone pose a significant barrier to internal migration.[25]

Policy can play an important role in supporting regions whose fortunes have fallen behind. Development support for weaker regions has, of course, a long history, with mixed success. A full review of historical policy initiatives is beyond the scope of this report. Nonetheless, recent research points to a few considerations that are important when designing regional support policies:[26]

- Ideally, regional development strategies should seek to build on existing capabilities and advantages of regions and aim at amplifying them through investments in infrastructure, education and technology. Existing capabilities and advantages can take the form of relatively cheap land and labor and prevailing industrial capabilities, as well as reputational assets.
- Policy formulation should identify the key barriers toward growing existing capabilities and rely on the input of all relevant local stakeholders.
- Resulting development policies should undergo regular evaluation. The resulting evidence should guide the adaptation of future policies.

While not reversing the gravitational pull of successful regions, such policies can ensure that innovation-driven growth benefits economies as a whole. As such, they critically underpin the openness of national innovation systems.

Box 5.2 Israel's thriving innovation system: startup nation or startup region?

Israel has a thriving innovation economy. Relative to the size of its GDP, no other country spends more on R&D and attracts more venture capital investments. Most of the world's leading technology companies have established R&D centers in Israel to draw on the skills and experience available in the country's dynamic research community. In many fields – notably cybersecurity – Israeli companies set the trend. Its lively startup scene has earned Israel the nickname "Startup Nation."

Israel's vibrant innovation economy has been a key driving force behind the growth of the overall economy. From 2008 to 2018, Israel's economy grew by an average annual rate of 3.5 percent – again, far surpassing most developed economies.[27] Unemployment fell to a record low of 4 percent in 2018.[28]

Yet, the nickname masks the high geographical concentration of innovation activity in Israel. The Tel Aviv metropolitan area stands out as the clear champion region. It accounts for 77 percent of all startups and 60 percent of all high-tech jobs.[29] It hosts more than half of Israel's inventors listed in patent applications (see Figure 5.3).

Wages in the peripheral regions are around 35 percent lower than in Central Israel. Tel Aviv's dominance has even intensified in recent years. The region was responsible for more than two-thirds of the growth in high-tech employees between 2015 and 2017.[30] Tel Aviv is also highly connected to leading innovation hotspots around the world, offering, for example, nonstop flights to San Francisco.

As in other global innovation hotspots, Tel Aviv has seen rising concerns that the expansion of technology companies is driving up housing prices and widening income disparities.[31]

The Government of Israel recognizes that the gravitational pull of the Tel Aviv region reflects relative regional advantages and natural agglomeration forces. Yet it also realizes that this regional imbalance creates economic and social challenges. As a result, Israel's Innovation Authority has adopted a Strategy for an Innovation-Driven Economy in the Periphery.

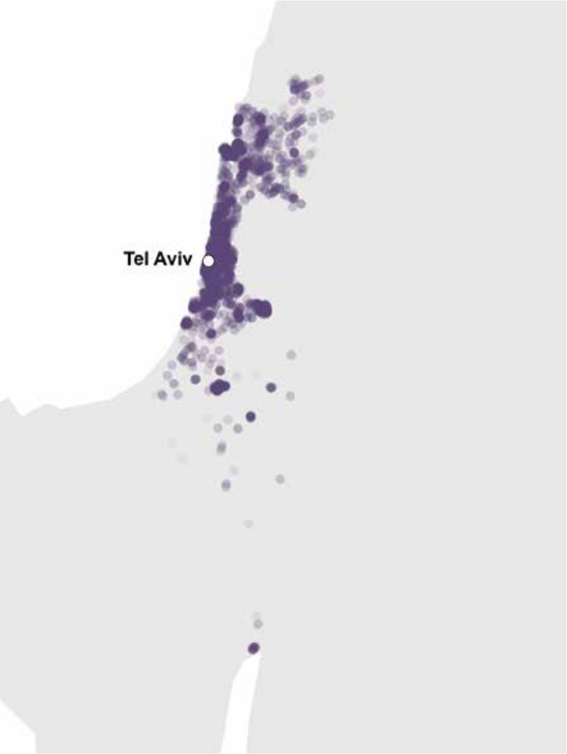
This strategy has four central pillars:[32]

- Connecting human capital in the periphery to leading high-tech companies;
- Promoting technological innovation in the periphery in the manufacturing, agriculture and food sectors;
- Encouraging entrepreneurship that draws on local academic institutions and other sources of home-grown knowledge and industrial expertise; and
- Strengthening the high-tech ecosystem in those regions – namely, Haifa, Jerusalem and Beersheba – that have the essential foundations for such an ecosystem.

These pillars seek both to reduce a growing shortage of high-skilled workers in the innovation economy and to promote the development of regions that currently are lagging to produce more balanced national growth.

The greater Tel Aviv area hosts most of Israel's inventors

Figure 5.3 Heat map of inventors listed in patent applications, 2008–2018



Source: WIPO based on PATSTAT and PCT data (see Technical Notes).
Notes: Patent figures based on international patent families.

Notes

1 See WIPO (2015).

2 See the case study on agricultural biotechnology in Chapter 4.

3 Visit home.cern. Israel is the only CERN member from outside of Europe.

4 See Krugman *et al*. (2018). Differences in productivity levels between countries are a third force driving specialization.

5 Differences in factor endowments can also explain patterns of international migration. Thus, highly skilled workers – say software engineers from India – tend to move to high-income economies where they are paid higher wages (see Krugman *et al*., 2018). Admittedly, lower wages of R&D personnel are but one motivation for multinational companies to locate R&D activities in developing economies; the growth potential of local markets is often another important factor (see Thursby and Thursby, 2006).

6 Noble prize-winning economist Kenneth Arrow first observed the public good nature of knowledge (Arrow, 1962). In addition to being non-rival in consumption, knowledge producers cannot – without intellectual property (IP) protection – exclude others from using knowledge communicated to the public. See WIPO (2011) for further discussion.

7 See WIPO (2019).

8 See Crescenzi *et al*. (2019).

9 See Cohen and Levinthal (1989) for an early contribution on the importance of absorptive capacity.

10 See von Hippel (1994).

11 Such arguments first became prominent in the 1980s when the rapid growth of East Asian economies was perceived to threaten the technological dominance of Western economies (see, e.g., Tyson, 1984).

12 Pritchett (1997) famously characterized the long-term historical trend as “divergence, big time.”

13 See WIPO (2015).

14 See Patel *et al*. (2018).

15 See Brander and Spencer (1985) for a seminal contribution.

16 See WIPO (2015).

17 See Bloom *et al*. (2019).

18 See Bloom *et al*. (2019). The authors also document declining R&D productivity when analyzing firm-level data across the U.S. economy. In addition, they consider and reject the possibility that the emergence of new technologies compensates for declining R&D productivity in existing technologies.

19 See Gordon (2018).

20 Visit en.wikipedia.org/wiki/International_Space_Station.

21 See Crescenzi *et al*. (2019).

22 See Ganong and Shoag (2017).

23 See Alcidi *et al*. (2018).

24 In reviewing two decades of research, Helpman (2018) concludes that globalization is responsible for only a small rise in inequality within nations.

25 See Ganong and Shoag (2017).

26 See Foray (2015) and Rodríguez-Pose (2018).

27 Based on constant 2010 U.S. dollar GDP values, as reported by the World Bank.

28 As per International Labour Organization country profile for Israel.

29 See Israel Innovation Authority (2019).

30 See Israel Innovation Authority (2019).

31 See Srivastava (2018).

32 See Israel Innovation Authority (2019).

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Technical notes

Country income groups

This report uses the World Bank income classification to refer to particular country groups. The classification is based on gross national income per capita in 2018 and establishes the following four groups: low-income economies (USD 1,025 or less); lower middle-income economies (USD 1,026 to USD 3,995); upper middle-income economies (USD 3,996 to USD 12,375); and high-income economies (USD 12,376 or more).

More information on this classification is available at data.worldbank.org/about/country-classifications

Country region groups

The country regions used in this report are closely based on the geographic regions from the Standard Country or Area Codes for Statistics Use, 1999 (Revision 4) known as M49 and published by the Statistics Division (UNDS) of the Department of Economic and Social Affairs, United Nations (UN). The full methodology can be found at unstats.un.org.

To simplify the analysis, some changes are introduced to this methodology. These are the following: *Western Europe* includes Andorra, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Spain, Sweden, Switzerland, and United Kingdom. *Central and Eastern Europe* includes all countries in the M49's *Northern* and *Southern Europe* regions not included in *Western Europe*. The geographical subregions *Southern Asia*, *Central Asia* and *South-eastern Asia* are grouped in one category, which also includes Mongolia.

Scientific publication data

The scientific publication data used in this report comes from 27,726,805 records published from 1998 to 2017 in the Science Citation Index Expanded (SCIE) of the Web of Science (WOS), the citation database operated by the Clarivate Analytics company. The analysis focuses on 23,789,354 observations referring only to scientific articles, conference proceedings, scientific abstracts and data papers. Scientific articles constitute the bulk of the resulting dataset.

Patent data

The patent data used in this report are from the European Patent Office's (EPO) Worldwide Patent Statistical Database (PATSTAT, April 2019) and WIPO's Patent Cooperation Treaty (PCT) collections. In the analyzed period (1970–2017), these sources account for 49,286,675 first patent filings and 26,626,660 subsequent patent filings, totaling 75,913,335 patent applications from 168 different patent offices.

The main unit of analysis is the first filing for a set of patent applications filed in one or more countries and claiming the same invention. Each set containing one first and, potentially, several subsequent filings is defined as a patent family. The analysis also distinguishes foreign-oriented patent families – also referred to as international patent families – from domestic-only ones. Foreign-oriented patent families concern those inventions for which the applicant has sought patent protection beyond its home patent office. This definition includes also patent applications by applicants filing only abroad, filing only through the PCT system or filing only at the EPO. Reciprocally, domestic-only patent families refer to those patent applications filed only at the applicant's home office – regardless of how many filings in the home office there are within the same family – without any subsequent foreign filing though the Paris or PCT routes. Likewise, patent applications with applicants of more than one origin are by definition foreign-oriented patent families. In addition, about 30 percent of the patent families relate only to utility model protection, which are mostly domestic only.

Unless otherwise stated, the report makes use of international patent families only as the unit of analysis for all patent statistics reported. This relates mostly to the incomplete coverage of the domestic-only patents (and utility models) of many national collections in PATSTAT. While the top national and international offices are usually well covered – namely U.S. Patent and Trademark Office (USPTO), Japan Patent Office (JPO), Korean Intellectual Property Office(KIPO), National Intellectual Property Administration of the People's Republic of China (CNIPA), EPO and WIPO – some other offices have limited coverage in PATSTAT. For instance, the coverage in PATSTAT of national collection data from some top 20 patent offices – such as India, Indonesia, Iran (Islamic Republic of), Mexico and Turkey – is limited. As a result, the report makes use of the information of 8,955,990 international patent families containing 35,582,650 different patent applications.

Geocoding

The geocoding – i.e., attributing the latitude and longitude to a given location – of the scientific publication and patent data was performed using all available information on addresses and already existing geocoding exercises for these data.

In the case of scientific publications, the report assumes that research conducted for any publication takes place at the institutions and organizations to which the authors declare their affiliation. Ninety-seven percent of all the available affiliation addresses were geocoded at the postal code or sub-city level. In the case of authors with more than one affiliation in the same publication, all different addresses were considered.

In the case of patents, 87 percent of the international patent families filed from 1976 to 2015 were geocoded. Most of the non-geocoded cases had no usable address information. As far as possible, the geocoding was applied to the inventors' addresses by using the most complete and reliable data source available within each patent family. In addition, the data were enriched with exiting geocoded patent data (see Yin and Motohashi, 2018; Ikeuchi *et al*., 2017; Li *et al*., 2014; de Rassenfosse *et al*., 2019; Morrison *et al*., 2017). All these sources and WIPO's geocoding were analyzed and consolidated to get the best possible geocoded data for each patent family. When there was more than one source for a given patent family, the following order of priority was given: (1) sources having information from the inventor (inventor principle); (2) sources having more inventors' addresses covered (coverage principle); (3) sources with the best geocoding resolution (resolution principle); (4) sources closest to the address country – e.g., entrusting Chinese addresses to CNIPA data, Japanese addresses to Japan Patent Office (JPO) data, etc. (local principle); and (5) manual check and ad hoc selection when two or more sources were still available. As a result, many inventor's addresses were geocoded at a precise level – i.e., street or block – but others only at the postal code or other sub-city level. Patent families containing more offices are more likely to be geocoded and at higher quality. This is another reason why the report relies only on international patent families. For more information, please refer to Miguelez *et al*. (2019).

Measuring innovation agglomeration

In order to handle the modifiable areal unit problem (MAUP) and its resulting statistical distortions, this report created two sets of ad hoc comparable areas to be used in place of administrative ones (see Ester *et al*., 1996). A first set – named global innovation hotspots (GIHs) – captures the most innovation-dense geographical areas of the world in terms of scientific articles or patent families per square kilometer (km). By definition, these areas are internationally comparable and geographically distinct. The same scientific publication or patent density determines the same hotspot anywhere in the world, although the threshold is different for scientific publication and patent data. No patent or scientific publication address can be in two hotspots at the same time.

A second set, named specialized niche clusters (SNCs), was created to avoid biases arising from some scientific or technological fields being overrepresented in the scientific publication and patent data, respectively. The SNCs capture areas with high innovation density in one or more specific scientific publication or patenting fields, and that otherwise have not met the criteria to be a global innovation hotspot (GIH). The resulting clusters are also distinct geographical areas, as the overlapping clusters for different fields are consolidated into one cluster. But they are only internationally comparable within their specific scientific or technological field (or fields).

As a result, the report identifies 174 GIHs and 313 SNCs worldwide. The detailed identification method is described as follows:

First, the points within GIHs are identified using the *Density-based spatial clustering of applications with noise* (DBSCAN) clustering algorithm applied separately to the geocoded patent and scientific publication data. The DBSCAN method requires two parameters – minimum radius and points – to establish the minimum acceptable density to form a candidate area. These two parameters were set differently for patents and scientific publications. The radius for scientific publication data was set to 23 km, which is the average commuting distance to work in OECD countries. Given the more precise geocoding of patent data, and based on visual inspection, the radius was set to the smaller value of 13 km. The minimum points parameter was set to the median patent and scientific publication density of all possible circumferences given the radius of each dataset. As a result, the minimum patent density of GIHs was set to 1,453 patents per 10 km^2 and the minimum scientific publication density is 3,328 scientific publications per 10 km^2.

Second, the resulting groups of points from DBSCAN are used to determine the candidate geographical areas – i.e., boundaries – of the GIHs. The borders of each scientific publication and patent agglomeration are determined using the *k*-nearest neighbors concave hull approach for each patent and scientific publication group of points (see Moreira and Santos, 2007). In order to avoid abnormal polygon shapes, the concave algorithm was set to have at least 75 percent of the convex area covered by all the outer points of a given group. In the handful of cases where the group had less than three coordinates, the polygon was set to a circumference of 13 km radius. The overlapping polygons are merged, keeping only the outer borders of all concerned agglomerations. However, if the overlap was less than 5 percent of either polygon, these were manually inspected and corrected. All patents and scientific articles within the resulting polygons are considered in the analysis, regardless whether they were or were not part of the DBSCAN results.

Third, the above method is repeated for 25 subsamples of the same publication and patent data, which refer to 12 scientific fields and 13 technological ones, respectively. The radius parameters are again set as 13 km for patents and 25 km for scientific publications. The minimum points are set to the median patent density of each of the 13 technological fields and the median scientific publication density of each of the 12 scientific fields of all possible circumferences given the radius of each dataset. From the resulting groups of each of these 25 iterations, only the points not contained within a GIH hotspot are kept to compute the concave polygon areas. From the resulting polygons, the overlapping ones are merged in the same way as mentioned above.

Mapping strategies

The patent mapping strategy for each of the two sectors – autonomous vehicles in Chapter 3 and plant biotechnologies in Chapter 4 – is based on prior studies and experts' suggestions. Whenever possible, each strategy relied on and was compared to existing equivalent scientific publication and patent mapping exercises. For more details please see Graff and Hamdan-Livramento (2019) and Zehtabchi (2019).

Autonomous vehicles (AV)

The AV mapping is based on a combination of patents in PATSTAT data and scientific articles in WoS SCIE data sampled based on patent classifications, scientific subjects and keywords. These are detailed as follows. The following IPC and CPC symbols were used to determine the AV-related patents and are based on prior patent landscapes of the UKIPO, EPO and JPO. Some of the CPC and IPC symbols were used in combination only with some keywords.

Standalone symbols: G05D 1/0088; G05D2201/0207; G05D2201/0212; G08G 1/22; B60L2260/40%; B60L2230%; B60K31/0008; B60K31/0008; B60K2031/0091; B60K31/0058; B60K31/0066; B60W2550/40; B60W2600%; G01S15/88; G06K9/00791; G06T2207/30252; G08G1/096791; G08G1/16; G08G1/22; H04L67/12; Y02P90/285.

Symbols in combination with keywords: B60L%; B60W%; B60W2030/%; B60W2040/%; B60W2050/%; B60W30/%; B60W40/%; B60W50/%; B60Y%; B60Y2200/11; B62D%; G01S13/93; G01S13/931; G01S15/93; G01S15/931/%; G01S17/88; G01S17/93; G01S17/936; G01S7/022; G01S7/4806; G05D1/02; G05D1/021/%; G08G1/16%; Y02T10/%; Y02T90/%.

Keywords: (ground | car | cars | lorri | lorry | road | street | highway | convoy | platoon | fleet), (autonomous | unmanned | driver[.]{0,}less | agv), and NOT (air | aer | drone | flight | flies | fly).

In the case of scientific publication data, an iterative process was applied. First, a keyword-based strategy was made on the abstracts of the WoS SCIE data by combining the following two lists of terms: (1) automated, autonomous, self-driving, driverless, unmanned, robotic, pilotless and unpiloted; and (2) vehicle, car, truck, taxi, shuttle, lorry, driving, transport(ation) and automobile.

Second, the tags declared by the authors of the resulting scientific articles were then manually inspected to build a new list of the following 40 terms: adaptive cruise control; advanced driver assistance system; automated driving system; automated lane change maneuver; automatic vehicle control; automatic vehicle following; automotive radar; automotive sensors; autonomous mobile robots; autonomous navigation; autonomous valet parking; autonomous vehicular networks; autonomous-vehicle lane; collision avoidance; crash avoidance; DARPA; DARPA urban challenge; Defense Advanced Research Projects Agency (DARPA) urban challenge; drivable-region detection; intelligent cruise control vehicles; intelligent unmanned autonomous system; LADAR; laser imaging detection and ranging; LIDAR; LIDAR object detection; light detection and ranging (LIDAR); look-ahead sensing; moving vehicle detection; obstacle avoidance; obstacle detection; pedestrian detection; pedestrian-crossing detection; platoon; predictive cruise control; unmanned ground vehicle; unmanned surface vehicles; vehicle automation; vehicle detection; vision-based guidance; wheeled robotic vehicle.

Third, the 40 terms were used in the abstracts and titles of articles to extract a new set. To avoid false positives, articles published in journals tagged in the following WoS subjects were excluded: Anatomy/Morphology; Art; Astronomy/Astrophysics; Audiology/Speech-Language Pathology; Behavioral Sciences; Biochemistry/Molecular Biology; Biodiversity/Conservation; Biophysics; Biotechnology/Applied Microbiology; Cardiovascular System/Cardiology; Cell Biology; Chemistry; Crystallography; Developmental Biology; Education/Educational Research; Emergency Medicine; Endocrinology/Metabolism; Entomology; Environmental Sciences/Ecology; Evolutionary Biology; Fisheries; Food Science/Technology; Forestry; Gastroenterology/Hepatology; General/Internal Medicine; Geochemistry/Geophysics; Geography; Geology; Geriatrics/Gerontology; Health Care Sciences/Services; Immunology; Infectious Diseases; Information Science/Library Science; Life Sciences/Biomedicine – other topics; Linguistics; Marine/Freshwater Biology; Medical Informatics; Medical Laboratory Technology; Meteorology/Atmospheric Sciences; Microbiology; Mineralogy; Mining/Mineral Processing; Neurosciences/Neurology; Nuclear Science/Technology; Nursing; Nutrition/Dietetics; Obstetrics/Gynecology; Oceanography; Ophthalmology; Orthopedics; Otorhinolaryngology; Pathology; Pediatrics; Pharmacology/Pharmacy; Physiology; Plant Sciences; Psychiatry; Psychology; Public Environmental/Occupational Health; Radiology Nuclear Medicine/Medical Imaging; Rehabilitation; Research/Experimental Medicine; Respiratory System; Rheumatology; Social Sciences – other topics; Sport Sciences; Surgery; Toxicology; Transplantation; Tropical Medicine; Urology/Nephrology; Veterinary Sciences; Water Resources; Zoology.

Crop biotechnologies

The crop biotechnology mapping is based on a combination of patents in PATSTAT data and scientific articles in WoS SCIE data sampled based on patent classifications, scientific journals and keywords. These are detailed as follows.

The following IPC and CPC symbols were used to determine the patents on each crop biotech category and the union of these constitute the total of crop biotech patents:

Crop genetic improvement: A01H1%; A01H3%; A01H4%; A01H5%; A01H6%; A01H7%; A01H17%; C12N5/04%; C12N5/14%; C12N15/05%; C12N15/29%; C12N15/79%; C12N15/82%; C12N15/83%; C12N15/84%; (C07K14/415% but not A61K%).

Pest control in crops: A01N63%; A01N65%; C12N15/31%; C12N/32%; (C07K14/325% but not A61K%).

Soil fertility: C05F%.

Climate change: Y02A40/146; Y02A40/162; Y0240/164.

The scientific publications were extracted from top plant biotechnology scientific journals and from the conjunction of top scientific journals for agriculture biotechnology and keywords. These are:

(1) All articles from the following top plant biotechnology journals: *Agri Gene*; *Crop Science*; *Euphytica*; *Genetics, Selection, and Evolution*; *Journal of Experimental Botany*; *Journal of Plant Physiology*; *New Phytologist*; *Physiologia Plantarum*; *Plant and Cell Physiology*; *Plant Cell*; *Plant Cell and Environment*; *Plant Cell Reports*; *Plant Journal*; *Plant Molecular Biology*; *Plant Physiology*; *Plant Physiology and Biochemistry*; *Plant Science*; *Planta*.

(2) Top agriculture biotechnology scientific journals and keywords:

Top agriculture biotechnology scientific journals: *Biochemical and Biophysical Research Communications*; *Cell*; *Journal of Biological Chemistry*; *Journal of Biology*; *Journal of Cell Biology*; *Journal of Molecular Biology*; *Journal of the American Medical Association*; *Molecular and Cellular Biology*; *Nature*; *Nature Biotechnology*; *New England Journal of Medicine*; *PlosBio*; *Proceedings of the National Academy of Sciences of the USA*; *Science*; *The EMBO Journal*; *Theoretical and Applied Genetics*.

Keywords: abscisic acid; ACC oxidase; ACC synthase; aerenchyma; *agrobacterium rhizogenes*; *agrobacterium tumefaciens*; *agrobacterium*; alfalfa; ammonium; anther culture; anthocyanins; apoplast; arabidopsis;

*arbuscular mycorrhiza**; auxin; bacterial blight; banana; barley; *beta vulgaris*; *rachypodium distachyon*; brassica; bread wheat; breeding; breeding value; C-4 photosynthesis; canola; *capsicum annuum*; carrot; cassava; chickpea; chinese cabbage; chlorophyll a fluorescence; chloroplast DNA; citrus; *coffea arabica*; cold tolerance; common bean; conifer*; cotton; crossbreeding; *cucumis melo*; *cucumis sativus*; cytokinins; cytoplasmic male sterility; *daucus carota*; defoliation; distillers grains; doubled; downy mildew; drought resistance; ectomycorrhizal; eucalyptus; flaxseed; forage; fructan; fruit development; fruit quality; fruit ripening; fusarium; *fusarium graminearum*; *fusarium* head blight; garlic; genome; genotype x environment interaction; genotype; germplasm; gibberellins; glycine max; *gossypium hirsutum*; grain; grain filling; grain yield; grapevine; hairy root; haploid; *hevea brasiliensis*; high; *hordeum vulgare*; hypersensitive response; kiwifruit; leaf anatomy; leaf growth; leaf rust; legume; linseed; *lolium perenne*; *lycopersicon esculentum*; maize; male sterility; marker; *medicago truncatula*; methyl jasmonate; micropropagation; mycorrhiza*; *nicotiana tabacum*; nitrogen fixation; orchid; *oryza*; *oryza sativa*; osmotic adjustment; osmotic potential; pea; peach; pectin; pepper; perennial ryegrass; *phaseolus vulgaris*; phenotyping; phloem transport; *physcomitrella patens*; phytic acid; phytotoxicity; *picea abies*; *pinus*; *pinus pinaster*; *pinus taeda*; *pisum*; plant breeding; plant defence; plant regeneration; plant transformation; pollen development; pollen germination; pollen tube; potato; *prunus persica*; QTL*; QTL analysis; QTL mapping; QTLs; quantitative trait loc*; rapeseed; resveratrol; RFLP; rice; root elongation; root exudates; *rubisco activase*; rye; sap flow; seed; self-incompatibility; shoot regeneration; *solanum lycopersicum*; *solanum tuberosum*; somaclonal variation; somatic embryogenesis; sorghum; soybean; *spinacia oleracea*; stomatal conductance; strawberry; sucrose synthase; sugar beet; sugarcane; sunflower; suppression subtractive hybridization; tall fescue; *thlaspi caerulescens*; tomato; transgenic plant*; transgenic rice; transgenic tobacco; tritic*; *triticum aestivum*; *vicia faba*; *vitis vinifera*; water potential; water use efficiency; wheat; winter wheat; xylem sap; zea may*.

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Acronyms

ADAS	advanced driver assistance systems
ADS	automated driving systems
AHS	automated highway systems
AI	artificial intelligence
AV	autonomous vehicle
BIO	Biotechnology Innovation Organization
Bt	*Bacillus thuringiensis*
CAAS	China Academy of Agricultural Sciences
CBD	Convention on Biodiversity
CEO	chief executive officer
CERN	European Organization for Nuclear Research
CGIAR	Consultative Group for International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CMU	Carnegie Mellon University
CNRS	Conseil National de Recherche Scientifique
Commission	European Commission
CPC	Cooperative Patent Classification
CRISPR-Cas9	clustered regularly interspaced short palindromic repeats-CRISPR associated protein 9
CSAIL	MIT's Computer Science and Artificial Intelligence Laboratory
CTO	chief technology officer
C-V2X	cellular vehicle-to-everything
DARPA	Defense Advanced Research Projects Agency
DNA	deoxyribonucleic acid
ECJ	European Court of Justice
EMBRAPA	Brazilian Agricultural Research Corporation
EPA	U.S. Environmental Protection Agency
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FCA	Fiat Chrysler Automobiles
FDA	U.S. Food and Drug Administration
FDI	foreign direct investment
GDP	gross domestic product
GEO	genetically engineered organisms
GIH	global innovation hotspot
GIN	global innovation network
GIO	genetically improved organism
GM	General Motors
GMO	genetically modified organism
IARC	International Agriculture Research Center
ICT	information and communication technology
IP	intellectual property
IPC	International Patent Classification
IRRI	International Rice Research Institute
IT	information technologies
MaaS	Mobility-as-a-Service
MAUP	modifiable areal unit problem
MIT	Massachusetts Institute of Technology
MNC	multinational company
NARS	national agriculture research systems
NOAA	National Oceanic and Atmospheric Administration
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
PCT	Patent Cooperation Treaty
R&D	research and development
rDNA	recombinant DNA
S&T	Science and Technology
SCIE	Science Citation Index Expanded
SNC	specialized niche cluster
TRI	Toyota Research Institute
U.K.	United Kingdom
U.S.	United States of America
UN	United Nations
UPOV	Union for the Protection of New Varieties of Plants
USDA	U.S. Department of Agriculture
USPTO	U.S. Patent and Trademark Office
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VW	Volkswagen
WatCAR	Waterloo Centre for Automotive Research
WIPO	World Intellectual Property Organization
WTO	World Trade Organization