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# Innovation policy, trade and the digital challenge

This section focuses on innovation policy and discusses its economic rationales and impact on innovation. For innovation to take place, new knowledge has to be created through investment in research and it then diffuses through the education system or publications, patents and interchange of ideas. When firms or governments instigate technological progress by using this knowledge, or its embodiments via inventions, to change processes, behaviours or technologies, economic growth may be affected, depending on a number of variables. Within any country, the diffusion of new technology depends on institutions, the level of economic openness and investment in education and research.

## Contents



### Some key facts and findings

- Several market failures in innovative activity, such as coordination failures across industries, provide economic rationales for government intervention.
- Some of the characteristics of digital innovations, such as the fact that they can be applied in a wide range of sectors or that they become more valuable the more they are used, make a strong case for orienting government policy toward digital innovation.
- Innovation policies have the potential to enlarge market size, increase the degree of competition in the product market, increase the productivity of research and development and improve the capability of firms to benefit from it.
- Trade, foreign investment, migration and data policies shape incentives for companies to innovate by affecting market size and competition. They also allow domestic firms to access foreign technology and know-how.
- Innovation policies have cross-border effects that will increasingly intensify in the digital age. Government policies should be designed to minimize the negative effects without limiting potentially positive spill-overs.

## 1. Introduction

This section focuses on innovation policy, its economic rationales and how it affects innovation. Section B of this report has argued that, in many countries, a major feature of the rethinking of government polices since the global financial crisis has been the emphasis on innovation, to accelerate the transition into the digital age. As Curtis (2016) puts it,

> "the current debate and proposals on updated forms of industrial policy are less about market interventionism and more on technological innovation, productivity gaps, R&D, entrepreneurship, vertical specialization and agglomeration economies".

The broad definition of "innovation policy" from Section B is also used in this section. It combines the views of innovation policy of Edler *et al.* (2016) as "public intervention to support the generation and diffusion of innovation", and of the World Bank (2010) as "a set of policy actions in several policy areas [...] constituting a framework for innovation to occur, but also for the innovation to be marketed, and diffusion of the underlying knowledge". To the extent possible, the focus will be on digital innovation, which, following on from Section B, implies in a narrow sense the implementation of a new or significantly improved digital product, and in a broader sense the use of digital technologies to create a new product, process, marketing method or organizational method, or to improve existing ones (Nepelski, 2019).

For innovation to take place, new knowledge has to be created through investment in research. Once new knowledge is created, it diffuses through the education system or publications, patents and interchange of ideas. New knowledge has the characteristics of a public good: it is non-excludable and non-rival in consumption. Thus, new knowledge can, in principle, be available to anyone.

However, this is not necessarily the case for all new knowledge. Patents, for instance, make new knowledge excludable (although still non-rival in consumption). Furthermore, not all knowledge can be codified. There is an important tacit component of knowledge that is not easy to acquire but is often crucial for transforming the knowledge into new production technology or for follow-up innovation.

Only when firms or governments can use existing ideas (or the inventions into which they are embodied) to change the production process or consumers' habits, and to improve technologies, can any impact on a country's economic growth be expected as a result of technological progress. This impact depends on the speed and extent of the acquisition, learning, adaptation and diffusion of new technology. Firms may not be aware of all the possible technological alternatives available in the market, they may not be able to identify the technology that best suits their need, or they may find it too costly to adapt foreign technologies to their production process. The lack of skills or incompatible managerial practices are also obstacles for technology diffusion and upgrading. At the country level, the diffusion of technology is facilitated by an adequate institutional environment, openness, and investment in education and research.

To develop these ideas in a structured way, this section proposes a taxonomy of the economic rationales (discussed in Section C.2) and of the effects (discussed in sections C.3 and C.4) of innovation policy, with a focus on digital innovation. Table C.1 presents this taxonomy.

### (a) Types of market failures in innovative activity which rationalize government intervention

The starting point of the analysis is the discussion of why innovation policy is needed in the first place. Despite the key role of public bodies, like research institutes and universities, innovation largely takes place at the level of the firms, which invest in research and development (R&D) and create new ideas or adopt technologies developed abroad. There are, however, several reasons why governments may need to intervene to foster innovation. Economists explain the need for innovation policies on the basis of market failures that characterize innovative activity. As displayed in the top panel of Table C.1, five types of market failures in innovative activity rationalize government intervention.

First, the outcomes of innovation have the characteristics of public goods (non-excludable and non-rival in consumption). Public goods are supplied in inefficiently low quantities by the market because private returns are lower than social returns. The section discusses various applications of this basic insight, including the issue of the appropriability of returns from innovation, the public good nature of data, and the public good nature of digital innovation in the current COVID-19-related health crisis.

Second, some technologies find important applications and instigate further technical change in a wide range of sectors, if not all. The introduction and adoption of these general-purpose technologies (GPTs) is subject to a series of market failures: positive externalities (whereby the production and

**Table C.1: Taxonomy of the economic rationales and effects of innovation policy**

| **1. Types of market failures in innovative activity which rationalize government intervention** | **Examples in the digital age** |
|---|---|
| Public good aspects of technology | Imperfect appropriability of returns from digital innovation.<br><br>Public good nature of data. |
| Economy-wide spill-overs of general-purpose technology (GPT) | Externalities created by new digital technologies in industries connected by upstream-downstream relationships. |
| Financial frictions | Start-ups tend to face excessively costly external finance, although financial frictions may be less relevant in the digital economy than in the traditional economy. |
| Coordination failures | Digital products and services are complex sectors, and the innovation process is more collaborative than in the past, calling for increasing partnership between traditional industry, digital technology or other service providers and research institutions. |
| Network externalities, technology lock-in and "winner-takes-all" dynamics | Some digital products generate value when consumed together with other users, and the market fails to deliver the efficient network size.<br><br>The combination of Big Data and machine-learning creates large rents, strengthens leaders' dominance and deters further market entry. |
| **2. Types of policies affecting innovation based on the factors they target** | |
| Policies affecting market size | Increased access to foreign markets can induce firms to increase spending on computers and software. |
| Policies affecting the incentives to invest in R&D | A larger supply of highly skilled immigrants increases innovation outcomes (i.e. patents) in ICT sectors. |
| Policies affecting the appropriability of research results | Intellectual property protection aimed at keeping open source software non-excludable allows high quality open source contributions to be widely adopted in a short time span. |
| Policies affecting product market structure | Wireline speeds are often higher in markets with two or more wireline internet service providers (ISPs) than with a single wireline ISP. |
| **3. Cross-border spill-overs of innovation policy** | |
| Knowledge spill-overs and technology diffusion | Digital innovations in one country can benefit the innovation activity of all other countries since they increase the global stock of knowledge. |
| Strategic government policy | In imperfectly competitive digital markets, policies can shift rents or profit from a producer in one country to a producer in another. |
| Competition for scarce resources | Tax incentives to attract headquarters of digital companies have "beggar-thy-neighbour" effects. |
| Supply and demand effects | Local content requirements for smartphones apps reduce the demand for foreign apps and can harm foreign producers. |
| Inter-industry linkages | Downstream digitally enabled industries across the world can benefit from productivity gains in upstream supplying industries like IT or electronic equipment due to innovation policy in one country. |

*Source*: Authors.

consumption of these technologies benefits a third party not directly involved in the market transaction) leading to their under-provision; coordination failures across industries connected by an upstream-downstream relationship; and some public good aspects of infrastructural GPTs. This section shows that digital technologies are indeed GPTs, and that the above-mentioned market failures provide economic rationales for government intervention.

Third, innovative activity is characterized by asymmetric information (i.e. an information gap) between the potential innovator and the potential financer. Consequently, an innovative entrepreneur may not have access to the required sources of finance (funding gap). Because of these financial frictions, R&D investment will be underfunded, and government financing of innovation may be justified on these grounds. This section argues that although the problem may be less relevant than in the traditional economy, it still exists in the digital economy.

Fourth, complex activities like innovation are subject to coordination failures among stakeholders. It may not be possible to attain a more desirable economic equilibrium if stakeholders do not coordinate their decision-making. Government action in this regard may be justified by the need to coordinate the different parties involved in the innovation process, ensuring that all the required complementary advances have been developed and are available in the market. For instance, to support the economic development of digital economy, the government may need to intervene to coordinate the co-financing of communication infrastructures.

Fifth, in situations where the value of a network increases with additional users (which are defined as network effects or, equivalently, network externalities – see Katz and Shapiro, 1985), governments may want to intervene because there is a gap between the private and the social value of joining the network, which leads to inefficiently small networks. Government intervention may further be warranted to address the risk of anti-competitive behaviour by "winners" that take the whole market and dynamic inefficiencies in networks where, because of government-mandated or *de facto* standardization, a single technology dominates the whole market.

These rationales for government intervention are even more relevant in digital markets, where the combination of Big Data and machine-learning magnifies "winner-takes-all" dynamics creating large rents, i.e. revenues exceeding total costs including the opportunity cost (or normal profit) (McConnell and Brue, 2005). These rents strengthen leaders' dominance and deter further market entry, thus hindering innovation.

### (b) Types of policies affecting innovation based on the factors they target

The existence of a market failure justifies government intervention. However, there is no guarantee that such intervention will succeed in delivering better outcomes, because designing appropriate innovation policies is difficult (Bloom, Van Reenen and Williams, 2019). The effectiveness of innovation policies is therefore an empirical question, which is tackled in Section C.3. As shown in Section B, the toolkit of policies to promote innovation is vast, because there are many factors that affect the innovation activity in the economy. The central panel of Table C.1 categorizes policies affecting innovation based on the factors they target.

First, a firm's decision to invest in R&D is affected by market size. When the market is large, firms have a greater incentive to innovate as their potential profits are larger. Increased access to foreign markets and government procurement in innovative sectors or activities, by enlarging the size of the market, can provide additional incentives for firms to invest in R&D and innovate.

Second, higher productivity of R&D also increases the incentives to invest in R&D. Several of the policies discussed in this section are likely to spur innovation through their impact on R&D productivity. These include: government tax incentives and R&D grants; policies favouring the supply of the type of human capital, both native and foreign-born, that is, those most involved in innovative activities, such as science, technology, engineering and mathematics (STEM) graduates; policies that favour the agglomeration of innovative activity, and more broadly all policies that allow inventors to benefit from research produced by others via knowledge spill-overs, such as interactions with foreign buyers and suppliers, global R&D networks, business travel and open data flows; and horizontal policies that create an innovation-friendly environment, such as the creation and maintenance of high-speed broadband.

Third, appropriability of research results is important. The extent to which firms can benefit from the reward of the results of their research determines their willingness to invest in R&D. This dimension is determined by two aspects: the nature of innovation (if it can be easily imitated/upgraded by competitors or not) and the degree of legal protection granted to the innovation through the intellectual property (IP) system. This latter aspect is clearly determined by policy choices.

Fourth, product market structure matters. The degree of competition in the product market affects the potential benefits of R&D investment because it determines the level of profits and the likelihood of displacing competitors. Trade policy and how it affects foreign firms' access to domestic markets is one of the factors that shapes the competitive environment. Another factor is the regulation of competition.

The five rationales for innovation policy in the top panel of Table C.1 are related to the four types of policies in the central panel of Table C.1. The public good nature of knowledge, the GPT nature of some technologies, financial frictions, coordination failures and network externalities lead to under-provision of innovation relative to socially optimal levels. Innovation policies that enlarge market size, increase the productivity of R&D, and ensure the appropriability of research investments, by filling, or reducing, the gap between the social and private returns to innovation, increase innovation investment above the inefficiently low levels delivered by the market.

In the presence of network externalities, there are incentives for firms that have managed to capture large shares of the market (the "winners") to engage in anti-competitive behaviour in order to keep their dominant position.[1] This also entails the risk of technology lock-ins (see Section C.2(e)), a dynamic inefficiency because technologies that have become obsolete over time might still be in place. Policies that ensure that markets are contestable, and policies that regulate the abuse of dominant position, address these issues.

### (c) Cross-border spill-overs of innovation policy

Innovation policies can, and do, have an impact on other countries. These spill-over effects, which can be positive or negative, are partly based on the same factors that provide an economic rationale for innovation policy, ranging from knowledge spill-overs to inter-industry linkages, but there are also additional externalities such as competition for scarce resources. The bottom panel of Table C.1 displays the cross-border spill-overs of innovation policy that are discussed in Section C.4.

First, knowledge spill-overs and technology diffusion across borders imply that innovation in one country can benefit the innovation activity of all other countries, since it increases the global stock of knowledge.

Second, in imperfectly competitive markets different policy tools, while affecting innovation, can shift rents from a producer in one country to a producer in another. That is, innovation policy can act as strategic trade policy.

Third, innovation policy (in the form of tax competition) that attracts scarce factors of production such as "superstar" investors, or that imposes localization requirements on data, or that offers tax incentives to attract company headquarters, is likely to harm other economies by reducing their capacity to invest in R&D.

Fourth, supply and demand effects can also lead to cross-border spill-overs. If innovation policy in a large country increases the competitiveness of domestic producers on world markets, world prices may decrease. This benefits foreign consumers while harming foreign producers. If innovation policy raises aggregate productivity in a large country, its import demand increases, and so do world prices. This benefits foreign producers while harming foreign consumers.

Fifth, cross-border inter-industry linkages (i.e. global value chains (GVCs)) can magnify the cross-border effects of innovation policies. Innovation in upstream (downstream) industries can benefit or harm foreign downstream (upstream) industries, depending on their effects on the price and availability of inputs.

It should be noted that different innovation policies may imply different cross-border spill-overs. When spill-overs are both positive and negative, for instance when a policy creates knowledge spill-overs but attracts scarce resources to the innovation production function, what matters is the net effect of such spill-overs.

This is especially the case in the digital age, in which, as argued in Section C.4, both positive and negative cross-border spill-overs are likely to intensify. An a priori determination of whether innovation policy in one country benefits or harms other countries' welfare is therefore inherently difficult.

## 2. The rationale for innovation policy in the digital era

Section B has shown that government policies have shifted to support the digital economy. These policies take various forms, including direct R&D incentives, infrastructural investments to support digital connectivity and data-sharing regulations to balance the need for data and the protection of privacy.

Section C.2 focuses on the rationale for innovation policies, pointing to what is new in the digital era. In so doing, it refers to a broad concept of innovation that includes not only policies that may help with invention, but also policies that may foster the diffusion of innovation.

While recognizing the key role that firms play in innovation, economists identify a number of reasons why governments may need to intervene to foster innovation. Firms invest in R&D and create new ideas or adopt technologies developed abroad. Firms operating in the digital technology field were among those with higher R&D investments in 2017 (Hernández *et al.*, 2019), confirming that research is a factor in being and remaining innovative. Yet, investments in innovation in some circumstances may be suboptimal if left only to market forces.

Economists explain the need for innovation policies on the ground of market failures. These can be due to externalities, asymmetric information or coordination failures.

Markets can fail and generate too little innovation because new ideas, new products or new technologies in a particular sector can be used by firms in that sector to create other ideas or can be used by firms in other sectors (that is, there are externalities of innovation), but with the innovator not basing decisions to invest in research on economy-wide benefits. Without government intervention, the innovator might therefore invest too little compared to the socially optimal level of investment (i.e. the level of investment that would be made if its economy-wide benefits were taken into account).

Innovators may also invest too little because they do not manage to raise adequate funding from financial institutions (financial frictions and asymmetries of information between the innovator and the financial institution can be the root cause if this problem) or because they need other technologies or infrastructure in place for their investment to generate adequate returns (coordination failure).

Finally, governments may need to intervene to prevent innovators from gaining excessive power and creating obstacles to the entry of new firms into the market (this is the case of network externalities and winner-takes-all dynamics). Section C.2 discusses each of the rationales for government intervention in the light of the characteristics of digital technologies.

A key message of Section C.2 is that some of the rationales for innovation policies are particularly relevant in the case of digital innovations. This is because:

- Big Data, a key input in digital technology innovation, present public good characteristics;
- digital technologies are GPTs and generate large benefits across the whole economy;
- digital products are complex and suffer from coordination failures;
- network effects may induce anti-competitive behaviour and deter innovation;
- network effects may require standards to be set for the market to have the sufficient size to deploy the innovation;
- large rents (revenues) may represent an incentive for strategic competition between countries; and
- the adoption of digital technologies may deliver public policy objectives.

In light of the above, digital innovation policies are likely to take several forms, such as R&D subsidies, competition policy, IP regulation, data policies and standards-setting.

## (a) The public good nature of creating and using digital technologies

### *(i) The issue of appropriation of returns from digital innovation*

One argument often used to justify government's subsidies for firms' R&D or the strengthening of the intellectual property rights (IPR) regime to protect profits stemming from innovation is that innovation creates knowledge. Knowledge has an important public good component: it is non-rival and non-excludable. When a scientific discovery is published, everyone can access the information and eventually use it to create new knowledge. This creates a wedge between private returns and social returns to innovation. The latter are larger because better knowledge increases long-run economic growth.

Thus, there is too little investment in R&D relative to the socially optimal level. Some economists estimate social rates of return to R&D between 30 and 50 per cent compared to private returns of between 7 and 15 per cent (Hall *et al.* 2010). If left to the market alone, public goods are underprovided by private actors, therefore public intervention is economically justified.

Knowledge created by digital innovation is no different from knowledge created in the traditional economy, with the creation of a new product or process. When the patent relevant to a new artificial intelligence (AI) device is filed, its knowledge is codified, public and can be used as an input for other innovations. Knowledge diffusion is key to fostering growth, but it reduces private returns for R&D investments. This problem for innovators is similar to that of pioneer entrepreneurs in developing countries who adapt a foreign digital innovation to the local market (see Box C.1).

However, as for the traditional economy, not all knowledge generated in the digital economy is codified. There is an important tacit component of knowledge (i.e. knowledge that cannot be codified in a patent, say) that is not easy to acquire. After the first innovation there is a process of improvement of the original idea developed through the interaction between the innovating firms, consumers and suppliers. This is essential in order to move from the new idea to the know-how of how to develop a new product or implement a new process innovation. This require capabilities that are not easy to appropriate (Dodgson, 2017). Intergenerational differences in the ability to use new technologies show

**Box C.1: Self-discovery and the pioneer entrepreneur in developing countries**

Although the diffusion of knowledge created by an innovation is key to fostering economic growth, it reduces the returns for the original innovators. A similar problem is faced by pioneer entrepreneurs in developing countries who discover that an existing foreign technology can be utilized profitably at home. There are large social benefits associated with "self-discovery", i.e. the process through which a less-developed economy initially specialized in traditional activities discovers, as a result of adapting foreign technology to local production, the set of modern activities in which it has comparative advantage (Hausmann and Rodrik, 2003). This is because the knowledge acquired by the pioneer entrepreneur can orient the investments of other entrepreneurs – in other words, other entrepreneurs can quickly emulate the discovery.

The initial entrepreneur who makes the discovery, however, can capture only a small part of the social value that this knowledge generates. Adapting new technologies to local conditions, especially in developing countries, is costly. As with any new invention, the first entrepreneur who adapts a new technology to local conditions may not be able to capture all the benefits because the technology may diffuse to his/her competitors. In the economy, there will thus be too little self-discovery, and consequently too little diversification into modern activities. However, policies that reduce the wedge between private and social benefits of self-discovery will increase this type of diversification and increase national welfare.

In their review of technology transfer, Evenson and Westphal (1995, p. 2261) describe the case of rice-threshing technology:

> "… the key activity enabling Philippine rice producers to benefit from rice threshing technology developed in Japan was the adaptive invention of a prototype thresher at IRRI [the International Rice Research Institute]. Using this prototype, local inventors made the specific adaptations required to enable the economic use of threshers in the many different circumstances in which they are now used in the Philippines".

Hausmann and Rodrik (2003) argue that the key to this success was the fact that IRRI is a non-profit, public entity. As a private producer, it would have been unable to appropriate much of the social returns due to the rapid entry of imitators.

It is hard to say to what extent this argument applies to digital technologies. When a foreign digital technology (an application used for car-sharing, for example) is adapted to local conditions by the local pioneer entrepreneur who discovers that the idea has a market in the domestic economy, the idea can easily be imitated. The fact that the returns on the innovation cannot be fully appropriated by the pioneer can prevent firms from investing in innovation, thus slowing the process of modernization. As argued by Hausmann and Rodrik (2003), the policy issue here is that, while in general, governments may have legal frameworks to protect the rights of innovators, they do not have in place similar regimes for self-discoverers. Yet, as discussed for open sources and music streaming, there are solutions that digital markets have devised.

that capabilities are not necessarily simple to acquire in the context of digital technologies. Tacit knowledge is a way in which an innovator retains some of the returns to innovation. However, typically, it is not a solution to the problem of under-provision of innovation.

In some cases, markets appear to have found some solutions to the issue of the appropriation of returns from digital innovation. For example, music streaming, like a typical public good, is non-rival (since one person listening to the music does not prevent another person from listening to the same music) and non-excludable (since, once a certain piece of music is put online, it is difficult to stop someone from listening to that piece). Innovators' inability to appropriate the profits generated by the new musical creation would typically imply that the service is under-provided (too few new songs go on streaming) and call for public intervention. However, the industry has found solutions: it collects revenue by selling advertising (which is an indirect way of charging listeners by taking up some of their time) or by charging a subscription for streaming music without commercials (in this case technology, through digital rights management tools, has helped to make the product excludable).

The development of open-source economics, of which software is the principal example, is another case of digital innovation that, although being a public good, has evolved without public intervention. The network environment, within which developers of open source software operate, makes it possible to organize production in a decentralized manner among individuals who cooperate with each other and share resources and outputs, without working for the same organization. At the level of the individual, the incentives to develop open-source software may stem from altruistic reasons or be related to leisure activity (some contribute to open-source projects simply because they enjoy it). But there can be also economic factors, such as improving a person's reputation with a view to obtaining access to a better job or capital. A company can also have an incentive to develop open source software in order to attract talented human resources.

### *(ii) The public good nature of data*

In the case of digital technologies, inefficiencies generated by the public good nature of data (a key input in digital innovation) can take the form of insufficient data collection, processing and sharing. Consider the case of a private company developing an algorithm to help diagnose COVID-19. The algorithm can be trained using information from patients with COVID-19 symptoms and comparing it with the pathology reports and outcomes of diagnosed patients. The company can buy and exclusively use information collected by hospitals from all patients in its network to train the algorithm. The hospital will collect data, pay the software company and provide a better service to its patients. But the service provided to patients would be clearly inferior to one generated by a situation where many companies around the world compete to develop algorithms to analyse freely available information from all patients in the country or in the world. The software based on larger samples could help doctors everywhere better treat patients and save lives.

The current COVID-19 crisis has highlighted the importance of rapidity and openness in data and research results. One key lesson from the crisis is that data-sharing helps the advancement of science. The problem is that when data are public, gains for a single company to develop an algorithm may not be sufficient to generate the broad use that is beneficial to society, because other companies may provide the same software at a cheaper price. This reduces the incentives to collect and process data. The issue of data ownership is key. In a recent paper, Jones and Tonetti (2019) argue that consumers' ownership of data can address this problem. Many governments have outlined data strategies to create an enabling legislative framework for data governance, make available public sector data for all market players, and provide incentives for data collection, processing and sharing across sectors.

These policies need however to also take into account the risks associated with data-sharing. These risks can be intrusion into private lives or the use of technologies for criminal purposes. A number of governments recently associated with a lack of transparency in decision-making, gender-based or other kinds of discrimination, issued regulations to address privacy and security concerns. The European Union, for example, issued the General Data Protection Regulations (GDPR) in 2018 to address data protection and privacy. The US State of California recently passed the California Consumer Privacy Act (CCPA) intended to enhance privacy and consumer protection.

### *(iii) The social benefits of using digital innovations for innovation policies in the context of COVID-19*

There are also non-economic reasons for innovation policies. Governments can invest in new technologies for societal missions, such as to reduce poverty and inequality, improve health, reduce environmental damage or address security considerations. In this case, private actors underinvest in digital innovation, not because the innovation itself has a public good dimension (as discussed in Section C.2(a)), but because digital innovation is instrumental to the provision of a public good or the pursue of a non-economic objective by the government. The use of digital innovation in the health sector during the COVID-19 pandemic is a good example.

The COVID-19 crisis has highlighted the important role that digital technologies can play both in building resilience and in helping to control the spread of the virus. A range of digital innovations have been developed to meet the challenge raised by the pandemic, from drones used for public health messaging to symptom checkers and tracing-and-tracking applications. Digital technologies have been increasingly used by firms and schools to cope with social distancing measures adopted by governments to limit the spread of the virus. Workers and students adapted to telework and online schooling in order to continue production and teaching activities under the lockdown. Telework helped firms to keep producing and to sustain supply chains with significantly positive economic results – the economic downturn is likely to be larger in sectors which did not offer the possibility to work remotely.

Governments have provided incentives for investment in new technologies to allow for teleworking and online schooling, with the twin goals of minimizing the negative effects of social distancing and of reducing the spread of COVID-19 (WTO, 2020c). These policies have responded to the need to address an unexpected and unprecedented shock for which the global economy was not ready.

The pandemic highlights both the great potential of digital innovations and the existing barriers to access and adopt new technologies. As countries adopted lockdown measures to limit the spread of COVID-19, individuals' computer access and digital skills, and the reliability of their internet and electricity services, determined their ability to work remotely, access online education services, and even purchase online medical supplies and home goods (see Box C.2). In some countries, tariffs as high as 35 per cent on computers and 40 per cent on telecommunications devices added to the difficulties for some of easily accessing digital technologies (WTO, 2020c).

The current pandemic has fostered the adoption of new practices. The technology for long-distance interactions and collaborations existed before, but its use was not sufficiently widespread. People continued physically to fly to attend conferences, board meetings and audit committees. The current crisis has offered the opportunity to observe the beneficial effects of teleworking and online schooling on the levels of pollution in the cities and on traffic congestion.

Will these habits be retained in the future? Will there be an increased use of these new technologies, given that their massive use in the current crisis has highlighted their potential in helping to deliver public goods, such as improved public health due to lower levels of urban pollution? Economic theory suggests that, in all these regards, private agents will continue to underinvest in digital technologies, as the investment decisions of private agents do not take into account the impact of their decisions on public goods. In other words, private agents are likely to underinvest in digital technologies for teleworking (even if they now realize that these technologies may help them to build resilience in the case of a shock, such as the COVID-19 crisis) because their investment decisions do not take into account the beneficial effects of teleworking on their firms and on urban traffic, nor the implications on the spread of disease.

## (b) Economy-wide spill-overs of general-purpose technology

Economists traditionally justify government intervention to support some industries as "special". This has to do with the fact that they generate economy-wide, inter-industry benefits, i.e. positive externalities. Technical innovations originating in particular industries find important applications and instigate further technical change in other economic sectors.

In these circumstances, economists show that forcing the economy toward the sector(s) generating positive externalities in the economy might improve welfare. This is because the losses from going against comparative advantage are dominated by the gains associated with the economy-wide externalities generated (Harrison and Rodríguez-Clare, 2010). This is one of the motivations for traditional support for industries such as steel or chemical, grounded in the fact that these industries provide critical inputs for several other industries.[2]

### *(i) Are digital technologies "special"?*

The development of the digital economy is transforming the world economy. Increasing innovation in products and processes linked to digital technologies is making it possible to collect, process, store and diffuse data automatically.

The digital economy is essential for global economic growth not because of its size – it only accounts for 6 to 8 per cent of value-added and at most 4 per cent of employment (IMF, 2018; Warwick and Nolan, 2014) – but because the global economy increasingly depends on digital goods, services and data to make it more productive.

Digital technologies are a form of GPT (Basu and Fernald, 2008). Important examples of GPTs from the past are the steam engine and electricity. GPTs are characterized by a wide range of applicability and substantial spill-overs to the rest of the economy (Jovanovic and Rousseau, 2005).

Like other GPTs, new digital technologies are used by most sectors, i.e. in agriculture, manufacturing and services. In agriculture, for example, machinery producers have started to offer digital agriculture services such as rural data and analytical services to better predict and manage agriculture investment; in the automotive industry, companies are offering digital after-sales services and new digitally managed ownership models (car-sharing). Retailers are investing in data collection and augmented reality to allow the consumer to get a better sense, simply through their mobile phone, of whether a piece of furniture, for example, might fit in their house; transportation services in urban areas increasingly rely on platforms and digital technology providers. AI technologies can be applied to sectors from medical to infrastructure services (see figures B.2 and B.5).

**Box C.2: Inclusiveness issues in the context of the COVID-19 pandemic**

The economic impact of the pandemic is expected to fall especially heavily on least-developed countries (LDCs), micro, small and medium-sized enterprises (MSMEs) and women. This is due to factors such as sectoral specialization, occupational characteristics and financial resources, as well as to inadequate access to digital infrastructure and insufficient IT skills.

The COVID-19 pandemic will severely impact LDCs. The fall in tourism revenues and in remittances from migrant workers from LDCs returning from host countries affected by the pandemic have significantly dried up critical sources of income for many countries (WTO, 2020a).

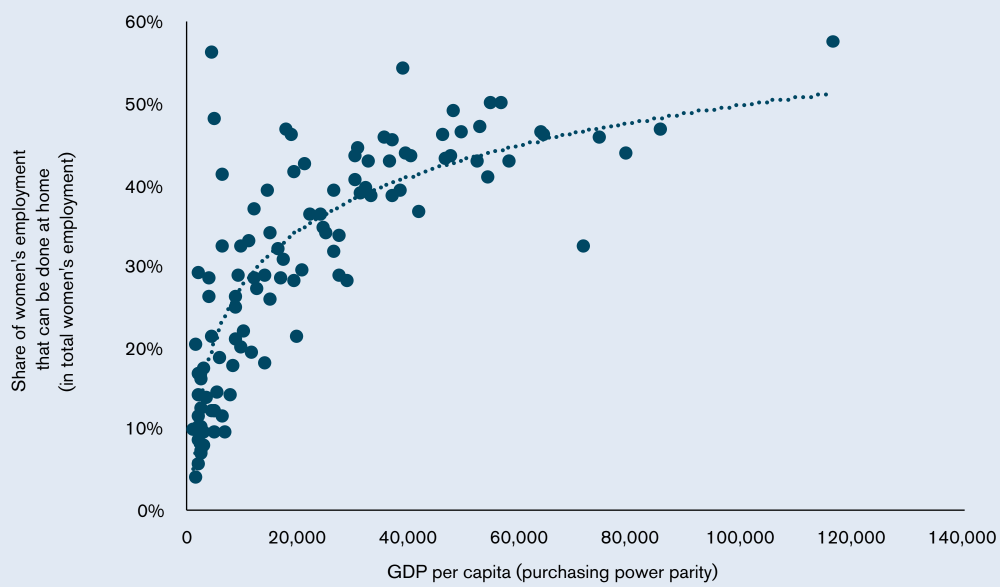
Preliminary evidence also suggests that the impact of the crisis is likely to be harsh for MSMEs. In the United States, firms with less than 50 workers laid off more than 25 per cent of their staff during the lockdown, compared to 15 to 20 per cent of staff being laid off in firms with more than 100 staff (Cajner *et al.*, 2020). In general, MSMEs are overrepresented in the hardest-hit sectors, such as accommodation, food services, and wholesale and retail services (OECD, 2020b) and, due to their financial constraints, they are more vulnerable to lockdown measures (WTO, 2020b).

The COVID-19 recession is also likely to have a harsher impact on women workers and entrepreneurs because the sectors in which they are economically active are among those which have been the worst affected by lockdown and distancing measures (e.g. textiles, apparel, footwear, tourism and business travel services) and because female entrepreneurs tend to own or manage small businesses. In addition, women tend disproportionally to bear household chores and childcare responsibilities that, in many countries, have been exacerbated by school closures (Alon *et al.*, 2020).

Digital tools allow certain jobs to be performed remotely, thus minimizing health risks. However, the jobs that can be performed remotely tend to be better-paying services jobs and tend to exist in a higher share in developed countries, rather than in developing or LDC economies (Dingel and Neiman, 2020). In other words, social distancing places a higher toll on developing countries because they have a higher share of occupations that cannot be done remotely.

Similarly, a large number of women tend to be more occupied in activities that require face-to-face interactions, such as health and retail activities, which prevent them from telecommuting, especially in lower-income countries (see Figure C.1). This is one of the reasons why the COVID-19 pandemic is likely to hit women particularly harshly (WTO, 2020a) – an issue to which regulators should pay attention (Bahri, 2020).

**Figure C.1: Women's jobs that can be done remotely increase with the level of income**




*Source*: WTO (2020a).

**Box C.2: Inclusiveness issues in the context of the COVID-19 pandemic *(continued)***

Thus, the digital divide crosses economies, genders and firm sizes. Limited access to digital technologies and lower IT skills rates further reduce teleworking and e-commerce opportunities in LDCs and MSMEs and for women, making them particularly vulnerable in the current crisis. In fact, the adoption of digital technologies is largely concentrated among highly productive firms that can complement digital technologies with good management and digital skills. The difference in adoption rates between more and less efficient firms is particularly pronounced in manufacturing (Andrews, Criscuolo and Gal, 2016; Bajgar *et al.*, 2019).

The main feature of GPTs is that they change the production process of the sectors using the new invention. For example, railroads transformed retailing by allowing nationwide catalogue sales (Chandler, 1977). Similarly, the availability of cheap computers and internet connections has generated complementary innovation in industries using information and communications technology (ICT), if only because they allow resources to be redeployed in a different way.

These complementary inventions in turn further increase demand for ICT. When industries are connected by an upstream-downstream relationship, some coordination is required. When a GPT is an infrastructure, as in the case of the road or the internet, congestion problems may arise. Externalities, coordination failures and the public good nature of the infrastructure of some digital technologies provide economic rationales for government intervention.

## (c) Financial frictions in a digital world

Financial frictions, such as those generated by information asymmetry about market conditions, may also inhibit firms from investing in innovation. Not all the actors in an economy have the same information about market conditions. Potential financers may have less information than inventors, making it more difficult for the financers to predict the returns from a potential investment in innovative ventures. As a consequence, an innovative entrepreneur may not have access to the required sources of finance, resulting in a funding gap. Because of these financial frictions, R&D investment may be underfunded.

Finance is not neutral. First, private finance tends to be directed toward applied research (i.e. research conducted to solve a specific problem, with, as a commercial objective, a new product or process) rather than basic research (i.e. research conducted with the aim of advancing a particular theory or knowledge). This is because basic scientific research is highly risky, requires large investments, and returns are unlikely to be seen in the short term. Private R&D, which aims to maximize profits in the short term, tends to be more concentrated on applied areas, neglecting general-purpose research. Yet innovation opportunities are driven by a strong interaction between basic and applied research. To fill this gap, governments invest in research with a broader scope and higher commercialization uncertainty. In the areas of biotech and renewable energy technologies, for example, it has been shown that venture capitalists enter markets many years after governments finance the earlier, higher-risk stages (Mazzucato and Semieniuk, 2016).

Second, finance is biased against MSMEs, especially start-ups, which tend to face excessively costly external finance. Frictions, including information asymmetry, asset intangibility and incomplete contracting, can lead to costly finance and thwart privately profitable investment opportunities (Holmström, 1989; Howell, 2017). Banks do not have enough historical information about the likelihood of a firm to reimburse loans when it is a new firm. The risks associated with an innovative product in the market are hard to identify and foresee in the conditions of a contract. All of this generates higher costs for start-up firms and is likely to reduce their investment in R&D. Yet there is evidence that start-ups play an important role in economic growth.[3] To address financial frictions and private finance's bias against new firms, government interventions often reduce the regulatory burden for start-ups, as well as facilitate access to finance for new and young firms (see Section B.3).

In a digital world, MSMEs which sell goods and services have less costly access to global markets. Digital MSMEs need skills, but investment in physical assets is less important in a digital world. Financial friction problems may be less relevant than the traditional economy, but they still exist.

## (d) Coordination failures of complex industries

The environment in which firms operate can act either as a resource or as an obstacle for innovation creation and diffusion. A successful innovation cycle and its impact on the economic performance of a country depends on a number of factors, such as demand for innovation, access to complementary knowledge and financial resources, and on the way these factors interact. Government actions in this regard consist of coordinating the different parties involved in the innovation process, ensuring that all the required complementary advances have been developed and are available in the market.

Complex industries – i.e. those that require more coordination among economic agents, according to Harrison and Rodriguez-Clare (2010) – are more subject to coordination failures. Such failures occur when a group of firms could achieve a more desirable economic equilibrium but fails to do so because the firms do not coordinate their decision-making. For example, private agents that want to develop hotels and restaurants in a particular location need each other in order to flourish, as well as a good transportation system to bring in tourists and supplies from different locations. Without coordination among all relevant actors, an attractive tourist site might not be properly developed, and the necessary infrastructure may not be provided. In order to launch the economic development of such an area and foster related tourism industries, the government may need to intervene to coordinate the co-financing of jointly required infrastructure by both groups of investors and offer its own contribution, given the public goods nature of roads and other transport-related investments.

Digital products and services are complex sectors, and the innovation process is more collaborative than in the past (Paunov and Planes-Satorra, 2019). Given the fast development of digital technologies, collaboration allows firms to gain access to a larger pool of expertise and skills, and to solve the skill gap. Beyond the traditional engagements, new forms of collaboration have been born to answer to the new needs of the digital age. Incubators or accelerators (see Section B for an explanation of these terms), generally used by firms to engage with start-ups, have come to be more oriented toward more innovative and technological activity. Walmart's Store N°8 is an example of a start-up incubator which aims to identify digital innovation in the retail sectors, offering virtual and augmented reality or drone product delivery.

The growing importance of services value-added and the role of digital technologies call for increasing partnerships between traditional industry, digital technology or other service providers and research institutions. In the automotive sector, for example, car manufacturers are collaborating with technology companies to improve their design processes and to develop autonomous cars (e.g. Toyota and Ford collaborate with Microsoft). In the retail industry, partnerships aim to create digitally connected stores or to develop voice-enabled shopping (e.g. Walmart and Google). There are also new forms of collaboration, such as crowdsourcing platforms, which are used by firms to search for ideas from outside those firms' cultures, to gain access to many skills and to reduce the time needed to find solutions. Generally, firms present their challenges online and different innovators present their proposals in response; the selected solution is then adopted by the firm. An intermediary platform which organizes the online competition is often used by these firms.

In order to support the economic development of digital economy, the government may need to intervene to coordinate the co-financing of communication infrastructures, given their public good character.

### (e) Network externalities, technology lock-in and "winner-takes-all" dynamics

Evolutionary economics stress the key role in the development process not only of creation, but also of the selection process that leads from a new idea to the elimination of the least promising solutions (Metcalfe, 1998). The selection process, especially in a world where network externalities prevail (that is, when the value of a new idea increases with additional users, see Katz and Shapiro, 1985), allows only one solution to emerge. This makes it difficult to implement changes when a certain evolutionary path has been selected. In an example offered by Edler and Fagerberg (2017), electrical and petrol cars were both viable options a century ago, and at the time, the selection process favoured cars which ran on petrol, and with this the development of an infrastructure that supported petrol cars. Nowadays, innovation toward more environmentally friendly (i.e. social welfare-enhancing) solutions is only viable thanks to government intervention, including through appropriate regulations. Path dependency (the fact that history matters, that is what happened in the past persists) makes government intervention needed in these circumstances. The problem is typical of sectors and technologies with network externalities.

Digital technologies are characterized by significant network externalities. The utility a user derives from joining a social network such as Facebook, for example, clearly depends on the number of other users in the same network. Some digital products have little value when consumed in isolation but generate value when consumed together with other users. There may also be indirect effects that give rise to network externalities.

Digital products are largely complementary goods or services – that is, they have value when consumed together. For example, a user purchasing a mobile phone with a pre-installed operation system will be affected by the number of other consumers purchasing similar mobile phones because the amount and variety of applications that will be supplied for use with that particular operating system will be influenced by the number of similar mobile phones that have been sold. The peculiarity of these systems is that consumers do not derive their utility only from the quantity and the quality of what they consume, but also on the availability and variety of complementary goods or on the number of people using the same product or compatible ones. So in fact, it is only once the number of subscriptions to a network reaches a certain critical mass point, and as the value of the network increases, that additional users will find it valuable to subscribe to that network.

The market in this case fails to deliver an efficient outcome, because the private benefit of joining a network differs from the social benefit. The social benefit of joining a network includes not only the private benefit of the new consumer, but also the benefit that old consumers derive from the enlargement of the network. It is in the interests of the consumer to join the most popular network (or the most popular good if there are complementarities). But lack of information, different preferences and firms' marketing actions may generate non-optimal pricing. Therefore, the equilibrium network size may be smaller than the social optimum because of the coordination problem generated by lack of information.

A government can intervene and set standards, thus solving the coordination problem. EU and US experiences in the wireless telecommunication industry show that a government-mandated standard can partially solve the coordination problem among consumers, as the critical mass of the network is reached very quickly, and consumers benefit from the network externalities associated with a larger market. When the Advanced Mobile Phone System (AMPS) was deployed as the American standard for the first generation of mobile phones, it quickly became a *de facto* world standard. The adoption of the Global System for Mobile Communications (GSM) as the pan-European standard for second-generation mobile phones in 1989 also fostered the diffusion of GSM outside Europe. As a result, GSM is the *de facto* global standard today.

If the government does not intervene, in network industries the market tends to determine a standard. A single technology tends to dominate the whole market once it has reached a certain size. Therefore, firms owning different technologies will engage in forceful competition to benefit from "winner-takes-all" gains, or will collaborate to invent a technology. In these cases, there is the risk of anticompetitive behaviour and dynamic inefficiencies.

Setting a standard, while essential to allow for technology diffusion, presents the risk of slowing down innovation if the standard turns out to be inefficient. However, the problem of inertia exists independently of whether the standard is government-mandated or set by the market's dominant firm (Katz and Shapiro, 1985). Switching costs, which affect consumers (such as the cost of replacing a cellular phone or breaking an existing contract), and carrier costs (such as the costs of replacing base stations, retraining employees and redesigning contracts) may lock in obsolete technologies even when the standard has been set by the government. The argument in support of a government-mandated standard should rest on good governance, i.e. such a standard is good when it is set with public interest in mind and is free from lobbying, or is set with the objective of avoiding anti-competitive behaviour.

As argued in Section B, in the case of digital technology, the combination of Big Data and machine-learning magnifies "winner-takes-all" dynamics. These dynamics create large incomes, strengthen leaders' dominance and deter further market entry, thus hindering innovation. Since digital technologies are global, and in the absence of adapters (an interface between technologies with different specifications), the question is whether there is need for international cooperation to set an international standard and/or to guarantee competition, a topic further elaborated in Section D.

Governments themselves have an incentive to intervene in markets and capture incomes (rents).[4] Supporting the development of digital technologies can be welfare-enhancing if the market exhibits rents. This is potentially one rationale behind the support of 5G technology that is observed in several economies. The competition between firms to become dominant becomes competition between countries when network externalities are global.

The issue of dominance in digital technologies is particularly relevant for developing countries (Foster and Azmeh, 2019). The global spread of the internet has not been matched by a big number of digital providers, firms and platforms. These still predominantly originate from a few countries, in which excellence is concentrated. Dominance generated by "winner-takes-all" dynamics also reinforces geographical inequality and makes such dynamics more persistent.

Data availability is another important issue for the geographical diffusion of technology. Data availability is key for innovation in business models and to process optimization in the supply chain. Data are collected from consumers, internal business processes or other sources, such as suppliers or market prices. This large amount of information allows large-scale experiments or virtual simulations to be conducted, favouring the customization or creation of products according to the preferences and needs of the market. Data flows allow the development of new business models; this was the case, for example, for Airbnb (an online peer-to-peer holiday rental marketplace company) and Uber (a platform that connects drivers with customers seeking services such as transport and food delivery). Real-time business information is used to make decisions and to optimize supply-chain activities.

Increasingly, data are essential to determine firms' competitiveness and a country's comparative advantage. Data are therefore often kept internal to the firm. This raises an important challenge of structural inequality within and across countries.

One way to foster innovation in a digital world is to favour knowledge-sharing by improving access to data and addressing the challenges arising from the need to respect privacy as well as security concerns. Digital technologies allow for the very rapid transfer and sharing of data and information across a large number of actors, and distance is not an issue. Open-source software and data flows promote spill-overs, fostering the diffusion of new technologies. From this perspective, the potential for knowledge spill-overs is likely to be greater than with traditional technologies. However, the non-rivalry of data can pose problems. Firms may choose to keep data in-house if they fear to lose the returns from their creative efforts.

## 3. The determinants of innovation in the digital era

This subsection considers the determinants of innovation in the digital era. As discussed in Section B, innovation can take various forms, such as the development and commercialization of new products, the improvement of existing products or of the production process for existing products. There are various factors that affect innovation activity in the economy and policies that aim to enhance innovation typically target one of them. In the taxonomy shown in Table C.1, the four main factors are market size, productivity of R&D, appropriability of research results, and product market structure.

This subsection provides an in-depth analysis of policies that can affect innovation and that fall under these four categories. In particular, policies that affect market size discussed in this subsection include increased access to foreign markets and government procurement. Policies that affect the productivity of R&D include: government tax incentives and R&D grants; policies favouring the supply of the type of human capital that is most involved in innovative activities; policies that favour the agglomeration of innovative activity, and more generally all policies that allow inventors to benefit from research produced by others via knowledge spill-overs; and horizontal policies that create an innovation-friendly environment, such as the creation and maintenance of high-speed broadband.

This subsection also discusses IP policies, which affect the appropriability of research results, and policies that affect product market structure – in particular trade policy and its effects on foreign firms' access to domestic markets, and policies that regulate competition.

It is worth noting at the onset that there is no one-size-fits-all approach of innovation policy, neither across countries nor within countries. Acemoglu, Aghion and Zilibotti (2006) show that R&D intensity is positively correlated with proximity to the world technology frontier (i.e. the extent to which a country lags behind the best-performing country in the adoption of the most recent innovations), consistent with the view that R&D is more important in industries or countries closer to the world technology frontier. They also show that, among countries that are in the process of development, market entry barriers are more harmful to the growth of those countries that are closer to the world technology frontier than to that of those countries that are far from the frontier. This is because, in the initial stages of economic development, countries tend to adopt an investment-based strategy to maximize investment. In this strategy, innovation is largely associated with adoption of existing technologies, which does not require a tough selection of high-quality entrepreneurs. As an economy approaches the world technology frontier, there is typically a switch to an innovation-based strategy, wherein innovation becomes more important than adaptation, and the selection of successful entrepreneurs becomes relatively more important.[5]

The set of policies that are relatively more appropriate for countries at different level of economic development does not only include policies that regulate competition, as in Acemoglu, Aghion and Zilibotti (2006), but also education policies: investment in higher education is relatively more effective (compared to investment in basic education) in rich economies than in poor ones. Furthermore, in economies, industries and firms far from the technology frontier, productivity is more likely to be spurred by improvements in management practices than by the set of innovation policies discussed in this subsection (Bloom, Van Reenen and Williams, 2019).

With these caveats in mind, the rest of this subsection discusses the empirical evidence on the impact of innovation polices that, via the market size, productivity of R&D, appropriability of research results and product market structure mechanisms outlined above, affect innovation. This subsection concludes with some insights on the wider economic implications of innovation policy, in particular its general equilibrium welfare impacts and its effects on inequality within economies.

### (a) Openness and competition

Trade, foreign investment, migration and data policies determine the openness of an economy. They affect the size of the markets that firms can access, shape the degree of competition in the domestic economy and determine the access of domestic firms to foreign technology, knowledge and know-how. A study of 27 emerging economies shows that both competition from foreign firms and linkages with foreign firms, through importing, exporting or supplying multinationals, increase product innovation, the adoption of new technologies and quality upgrading (Gorodnichenko, Svejnar and Terrell, 2010). This subsection provides provide detailed empirical evidence on the different channels that lie behind this positive effect of openness on innovation.

#### *(i) Improved access to foreign markets*

Larger markets increase the scale of production and revenues from innovation. This motivates firms to incur the (often sunk, i.e. already incurred and irrecuperable) costs of implementing new technology or investing in R&D. Bustos (2011) shows that an easier access to the Brazilian market after the establishment of MERCOSUR (i.e. the Southern Common Market) led Argentinian exporters to increase their spending on computers and software, technology transfers and patents, and on inputs into innovation activities. Similar reactions to increased export demand have been documented for Canadian and French firms by Lileeva and Trefler (2010) and by Aghion *et al.* (2019b), respectively. Based on data on exporting and R&D expenditure of electronics producers from Chinese Taipei, Aw, Roberts and Xu (2011) estimate that a reduction in the average tariff faced by exporters from approximately 10 to 5 per cent would increase the proportion of firms that invest in R&D by 2.5 percentage points after two years and 4.7 percentage points after 15 years. This is a sizeable effect given that only 18.2 per cent of plants in the sample conduct R&D.[6]

Furthermore, the effect of market expansion can ripple through the economy along the supply chain. When an exporter increases its production, its suppliers can benefit from the larger scale as well. Linarello (2018) provides some evidence that increased export opportunities for Chilean companies also positively affected the productivity of their suppliers.

Finally, interactions with foreign buyers can help knowledge diffusion. Atkin, Amit and Osman (2017) find that Egyptian artisanal rug producers that started exporting through an intermediary improved their production techniques and the quality of their rugs. The study shows that trade intermediaries do not only facilitate matching suppliers with foreign customers, but can also help transfer knowledge about techniques of production. The potential for large orders from a market that values high quality provided the motivation, and the information exchange via the intermediary provided the know-how for technology upgrading.

In conclusion, trade policies that result in a reduction of export costs increase firm profits. This in turn increases the expected profits from innovation and stimulates technology adoption and innovation activities in firms that benefit from the better market access. The expansion of export activities also increases the demand for inputs and can therefore motivate firms in their supply chain to upgrade their technology. Importantly for small and developing-country firms, interaction with foreign buyers facilitates technology transfer. Export promotion policies thus can improve firm performance, especially for small firms (Munch and Schaur, 2018).

#### *(ii) Imports of capital goods and intermediate inputs*

Trade enhances knowledge spill-overs through the diffusion of knowledge embodied in intermediate inputs. Cheaper imports raise productivity via learning, variety and quality effects. Several studies show that total factor productivity in an industry increases with imports of intermediate inputs with high technology content.

The pioneering work of Keller (2002) finds that foreign R&D, embodied in intermediate input imports, accounted for around 20 per cent of the total effect of R&D investment on productivity in eight Organisation for Economic Co-operation and Development (OECD) countries. Using international input-output data for 32 developed and emerging economies, Nishioka and Ripoll (2012) find positive spill-overs from R&D-intensive imports. Evidence from Indonesian firms suggests that a fall of 10 percentage point in input tariffs leads to a productivity gain of 12 per cent for firms that import their inputs (Amiti and Konings, 2007). A firm-level analysis from India suggests that India's tariff liberalization in the early 1990s accounted on average for 31 per cent of the new products introduced by domestic firms because it allowed them to access a larger variety of inputs (Goldberg *et al.*, 2010). Fieler, Eslava and Xu (2018) complement this evidence with the analysis of unilateral tariff liberalization in Colombia.

Liberalization of input trade stimulates both imports and innovation by lowering production costs. Firms can cut production costs and raise profits by sourcing inputs internationally. As discussed above, higher expected profits increase the incentives to invest in R&D and thus cheaper access to intermediate inputs spurs innovation (Bøler, Moxnes and Ulltveit-Moe, 2015). Firm-level studies for Argentina, Chile, Hungary and India confirm that better access to foreign intermediate inputs increases plant productivity (Gopinath and Neiman, 2014; Halpern, Koren and Szeidl, 2015; Kasahara and Rodrigue, 2008; Topalova and Khandelwal, 2011). Lane (2019) highlights the role of subsidized intermediate imports in the positive impact of the Republic of Korea's policy to promote its heavy chemical industry. He also shows that the impact of the government policy was transmitted along the supply chain, with a positive impact on downstream firms, which saw a decline in their input prices and increased capital investment.

### *(iii) Import competition*

Conceptually, there are forces pulling in two directions when it comes to the impact of increased competition on innovation. On one hand, competition erodes the profits of domestic firms, and hence their motivation and the availability of their internal funds to invest in innovation. It is the flipside of the argument concerning why export expansion increases innovation. On the other hand, domestic firms can escape competitive pressure by increasing productivity or differentiating their products from those of new competitors. Innovation and adoption of new technologies should thus increase among domestic firms.

The impact of increased competition may also depend on the initial conditions in the market. Escaping competition through innovation may be particularly relevant in industries where firms are similar in their technological levels. However, in industries where there is a technology leader with a tail of less competitive firms, increased competition may, in theory, lead to lower innovation activity (Aghion *et al.*, 2005).

The empirical evidence shows that, on balance, import competition increases innovation (Shu and Steinweider, 2019). Based on data from 27 emerging market economies, Gorodnichenko, Svejnar and Terrell (2010) find positive effects of foreign competition on innovation by domestic firms. These effects do not depend on the underlying degree of competition in the industry and they hold both for manufacturing and service sectors.[7] Evidence from Colombia shows that tariff liberalization has a strong positive impact on plant productivity. The impact is stronger for larger plants and plants in less competitive industries (Fernandes, 2007). Furthermore, import competition forced the least productive plants to exit the market, which had a large positive impact on aggregate productivity (Eslava *et al.*, 2013).

Comparing the different channels through which tariff liberalization affects firm performance, Amiti and Konings (2007) also find that a decline in tariff protection leads to an increase in the productivity of Indonesian producers, but the positive effects of lower input tariffs on the productivity of importing firms is at least twice as high. In other words, the imported inputs channel is stronger than the import competition channel. Topalova and Khandelwal (2011) come to similar conclusions in their study of Indian firms.

Turning to the impact of import competition on firms in high-income economies, Bloom, Draca and Van Reenen (2016) study the reaction of firms in 12 EU countries to competition from Chinese imports. They find that the firms most affected increased their innovation, measured by the number of patents. The intensified competition also forced the least productive firms out of the market and thus led to a reallocation of employment to technologically advanced firms. In combination, these two effects accounted for 14 per cent of European technology upgrading between 2000 and 2007.

In contrast, Chinese import competition had a negative impact on innovation activity in US firms (Autor *et al.*, forthcoming). The reduction in sales and profitability of import-competing firms led to their decline in R&D spending and hence patenting. The authors show that smaller and less capital-intensive firms were affected the most, which, as the authors argue, could eventually lead to a positive reallocation of resources to stronger firms. They also suggest that the difference in the reaction of EU and US firms can be due to different initial conditions of competition in the markets and the larger size of the import shock in the United States.

Innovation incentives, such as R&D subsidies, may help to ensure the positive impact of foreign competition on innovation in large high-income economies. Akcigit, Ates and Impullitti (2018) study the interaction between globalization and innovation in the United States in the 1970s and 1980s, when US firms faced intensified international competition due to the technological catch-up in Japan and in Western European countries. The study shows that R&D subsidies help domestic firms to escape competition through innovation, thus maximizing the welfare gains from globalization. Raising trade barriers, on the other hand, harms the economy in the longer run because it weakens the competitive pressure and hence decreases innovation incentives.

In conclusion, most empirical studies support the positive impact of trade liberalization on firm-level innovation. Some studies also hint at the importance of the ensuing resource reallocation towards more innovative firms. That is, trade liberalization can increase innovation in the economy not only by increasing innovative activity within firms but also by inducing a shift in resources to more innovative firms. Similarly, trade policy can affect the allocation of resources between more and less innovative industries. This is the focus of the infant industry argument that is discussed in Box C.3.

### *(iv) Global value chain participation*

As discussed in previous paragraphs, the interaction between domestic and foreign firms favours technological diffusion in two ways: (1) foreign buyers may provide incentives to local suppliers to adopt new technologies, and (2) inputs from foreign suppliers may embody advanced technologies.

Participation in international supply chains can be an even more powerful channel for technology transfer. International production sharing involves a high degree of interdependency between producers from different countries, as the production of a good in one country depends on the timely delivery of inputs from a factory abroad, and these inputs need to be perfectly compatible with the domestic production line. Therefore, foreign outsourcing firms are more willing to transfer the know-how, managerial practices and technology required for an efficient production of the outsourced input. The same argument applies also for firms that become part of a supply chain of foreign affiliates in the host country.

Using industry-level data for 25 countries, Piermartini and Rubínová (forthcoming) show that participation in international supply chains helps industries to benefit from R&D performed by their foreign partners. These international knowledge spill-overs boost domestic innovation, especially in emerging economies. Javorcik (2004) shows that supplying affiliates of foreign companies can increase the productivity of firms in a transition economy. She argues that it is the result of more stringent requirements on quality and timely delivery, combined with training for personnel and transfer of know-how. More recently, Alfaro-Urena, Manelici and Vasquez (2019) show that Costa Rican firms that started to supply foreign multinationals experienced strong and persistent improvement in their performance. Based on their survey of managers in both multinational corporations (MNCs) and local Costa Rican firms, they conclude that this positive impact is driven by a variety of inter-related transformations in the production process that lead to expansions in product scope with higher-quality products, better managerial and organizational practices, and improved reputations.

### *(v) Face-to-face interaction within global value chains and research networks*

Another reason why GVCs facilitate technology transfer is that they intensify face-to-face contacts between foreign firms and their suppliers. Firms in a production chain need to interact and coordinate to guarantee a smooth functioning of the chain. Consequently, high-skilled personnel often move within multinational firms across borders to assure technological as well as managerial cohesion across production units in different countries. This face-to-face communication facilitates the transfer of know-how and tacit knowledge.

A study by Hovhannisyan and Keller (2014) finds that a 10 per cent increase in business travel from the most innovative regions of the United States increased patenting in the destination country by about 0.2 per cent. Focusing on knowledge flows between US regions, Agrawal, Galasso and Oettl (2017) find that better connectedness facilitates the circulation of knowledge and, consequently, a 10 per cent increase in the number of interstate highways leads to a roughly 1.7 per cent increase in innovation as measured by patenting activity in the region. Box C.5 also provides further evidence of the positive effect of knowledge flows associated with business travel by migrant diasporas to their countries of origin.

**Box C.3: Trade policy as a tool to change the industry composition of an economy**

A long-standing debate in economics centres around the idea that temporary protection from foreign competition may help a domestic high-tech industry to become internationally competitive and expand production, thus increasing innovative activity and economic growth in the country. This so-called infant-industry argument is conditional on the supported sectors having potential economy-wide positive knowledge externalities but high initial production costs that decrease only progressively over time as a result of learning by doing (Aghion *et al.*, 2015).[8] Local content requirements often complement import protection.

An empirical assessment of the infant industry argument has been inherently difficult. As with any similar government policy intervention, the motivation to target a specific industry is usually unobservable to the researcher and creates endogeneity issues that complicate causal assessment of the policy. Moreover, even if the policy intervention is successful in boosting the targeted industry, such a result is not sufficient to claim that the policy was welfare-enhancing.

Recent literature has started to tackle the first issue and sheds some light on whether import protection boosted the protected industry's performance. As an example, Juhász (2018) focuses on the adoption of a technology that drove productivity and innovation in the 19th century – mechanized cotton spinning. She finds that French regions that were affected by the Napoleonic blockade, and thus could not import textiles from England, adopted mechanized cotton spindles faster than other regions. The author suggests that this first-mover advantage lasted for a century. The results can be interpreted in the light of external economies of scale[9] which imply that even temporary interventions may have a long-lasting impact on the location of an industry. Recent work by Hanlon (forthcoming) and Mitrunen (2019) comes to a similar conclusion in the context of other historical interventions.

Nunn and Trefler (2010) explore the hypothesis that due to path dependency, an initial protection of R&D-intensive industry (characterized by knowledge spill-overs) can lead to a higher per capita GDP growth. They find that productivity growth in a country is positively correlated with the tariff protection of sectors that are skill-intensive (a proxy for R&D-intensive sectors) and argue that at least 25 per cent of the correlation corresponds to a causal effect.

Overall, there is still very little evidence about the operation and mechanisms of infant industry policies. One emerging framework to study the impact of these policies builds on historical cases that clearly spell out the policy context and isolate specific mechanisms (Lane, 2020). While this approach can offer a clear assessment of past policies, more research is also needed into how the assumptions that underpin the infant industry argument – path dependency and positive economy-wide impact of certain industries – translate into the world in which economic growth is driven by fast-paced digital innovation.

In general, since tacit knowledge and know-how travel with people, business travel plays an important role in fostering productivity and economic growth. The importance of meeting and networking with other business or researchers is often reflected in government programmes targeted at promoting innovation (Edler and Fagerberg, 2017).

Knowledge spill-overs from universities and research centres increase with the mobility of scientists. However, knowledge diffusion is geographically limited if measured by citations to patents and scientific publications. A seminal study by Jaffe, Trajtenberg and Henderson (1993) shows a clear home bias in patent citations in the United States. This bias is not only at the country level but also at the state and even the county level. Belenzon and Schankerman (2013) confirm that knowledge spill-overs among US universities are strongly constrained by state borders, and show that these localization effects are the strongest in states with low interstate scientific labour mobility. However, Head, Li and Minondo (2019) argue that personal and professional ties foster knowledge flows, and that therefore the spatial concentration of knowledge spill-overs is driven by the fact that these ties are predominantly local. They show that if two mathematicians have a tie, such as past co-authorship or a common thesis advisor, current distance between them has little impact on the likelihood of one citing the other. Mobility of students and scientist fosters global ties and thus facilitates global knowledge spill-overs.

Consistent with the fall of travel and communication costs in the 1980s and 1990s, the localization of knowledge spill-overs has declined (Griffith, Lee and Van Reenen, 2011). The home bias nevertheless remains in sectors with strong external economies of scale, such as ICT technology.

Knowledge transfer can be a consequence of labour mobility, especially of researchers, engineers and other skilled workers, between employers. During the innovation process, workers develop and acquire new knowledge and competences, as well as an understanding of the implemented technologies. When they move from one firm to another, the new employer can benefit from this human capital (Breschi and Lissoni, 2001). This is another example of how knowledge generated in one country can foster economic growth in another country.

Global research networks promote the sharing of key scientific inputs, such as knowledge, equipment or data, and thus are essential for scientific and technological progress. Iaria, Schwarz and Waldinger (2018) use historical data to show that an interruption in scientific cooperation leads to a decline in the production of basic science and its technological application. For example, the First World War created a scientific schism between the Allies and the Central Powers that lasted until well after the war ended. During that time, the delivery of international journals was delayed and scientists from the Central Powers (i.e. Austria-Hungary, Bulgaria, Germany and the Ottoman Empire) were officially boycotted by their Allied peers (e.g. Great Britain, France, Italy, Japan, Russia and the United States) until 1926, which excluded them from international research associations and conferences. Iaria, Schwarz and Waldinger (2018) show that this led to a reduction in knowledge flows that were crucial for top-tier research. Consequently, scientists who relied on frontier research from abroad published fewer papers in top scientific journals, produced less Nobel Prize-nominated research, introduced fewer novel scientific words, and introduced fewer novel words that appeared in the text of subsequent patent grants.

Recent studies show that global R&D networks, often driven by R&D offshoring, enhance the innovative output of researchers in emerging and developing economies. For instance, they can explain the rapid increase in the number of Chinese and Indian patents granted in the United States (Branstetter, Li and Veloso, 2014; Miguélez, 2018). This illustrates the importance of international research networks in enhancing learning from the global pool of knowledge and the consequent economic growth.

### *(vi) Successful technology transfer and knowledge spill-overs*

While every economy can benefit from imports of high-quality inputs, more competitive domestic markets and access to large foreign markets, knowledge spill-overs that enhance innovation and the implementation of foreign technologies in domestic production are often conditional on the receiving party's capabilities to maximize their benefits. The major barriers to technology transfer are related to the specific characteristics of firms or to systemic problems that derive from the environment in which firms operate. Firms may not be aware of all the possible technological alternatives available in the market or may not be able to identify the technology that best suits their needs. A lack of skills or incompatible managerial practices are also obstacles for technology upgrading. At the country level, technology transfer is facilitated by the presence of an adequate institutional environment, openness, and investment into education and research.

To exploit a new foreign technology, firms need to have an adequate absorptive capacity. Absorptive capacity refers to the capacity to learn how to use a new technology, to learn about the principles of how it works, and to adapt a technology developed abroad to the local conditions of a country. The quality of education, the number of skilled workers and the resources spent on public research are some of the important factors that improve absorptive capacity in a country (Augier, Cadot and Dovis, 2013; Piermartini and Rubínová, forthcoming). Collaboration between industry and research institutions is also crucial for the adaptation of foreign technologies to domestic conditions.

Many technologies are developed in high-income economies by multinational companies and may fit best with the organizational and institutional environment of those economies. The successful implementation of new technologies in other economies or types of firms thus often requires a change in managerial practices. Giorcelli (2019) studies the effects of a Marshall Plan[10] project in the 1950s which provided some Italian firms with advanced American capital goods as well as management training. She shows that the new managerial expertise was instrumental to the persistent positive effect of new machines on firm performance.

Another study shows that even organizational differences, such as the type of labour contracts, can hamper the adoption of a new technology. Atkin *et al.* (2017) experimented with producers of footballs in Pakistan by teaching them a new technique that would reduce their material waste. To their surprise, only a very small number of firms implemented the technique. The reason was an incentive misalignment between workers and managers. Workers in most firms were paid by the piece, and implementing the new technique would have slowed them down, at least initially, leading to lower wages. Therefore, despite the potential of the technique to improve overall efficiency of production, workers resisted its adoption.

Digital technologies are no different. Even in high-income countries, the uptake of digital technologies lags behind policy goals. Making the most of digital technologies and successfully competing in digital innovation requires not only investment into equipment and skills, but also changes in the organizational structure and processes.

### *(vii) Open and transparent data policies*

In the digital age, what matters is not only openness to the flow of goods, services or people, but also to the associated data. As discussed extensively in WTO (2018a), data policy is a key to comparative advantage in the digital age because it drives the innovativeness and performance of digital firms. Its value and untapped potential for companies and governments has increased dramatically as new data extraction and analysis methods based on AI coincide with the exponential growth of data availability in the digital age. This has made data an important input for innovation across all sectors in the economy (Guellec and Paunov, 2018), as also highlighted in Section B.1. The market for data analytics has been estimated to grow on average by 40 per cent per year, and the immense value of data for innovation has been highlighted in a series of studies which show that firms that use Big Data for innovation exhibit productivity growth 5-10 per cent faster than other firms (OECD, 2015).

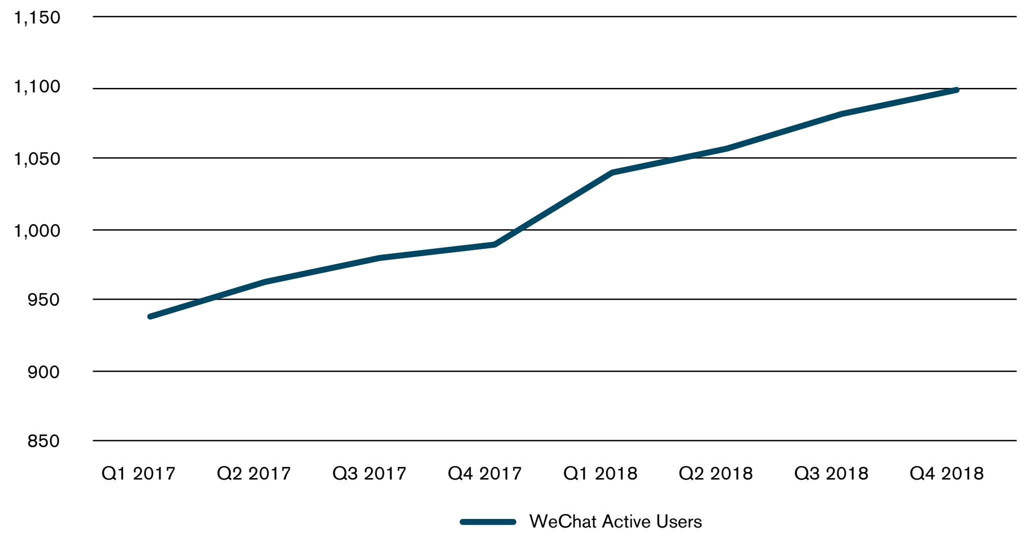
As a consequence, data policy, from data localization to web content or privacy regulation, can serve as an important tool in the innovation policy toolbox, even if data policy, especially concerning privacy protection, is often enacted for other legitimate policy objectives. In theory, restrictive data privacy policies can reduce the use of technologies that depend on data, and limit innovation that benefits from large and connectable datasets. However, they can also increase the supply of available data if they lead consumers to trust firms that collect data or if they cause foreign firms to transfer data to the intervening economy. In practice, however, the first effect seems to dominate, and less restrictive data privacy protection policies seem to benefit firms that use digital technologies (Goldfarb and Tucker, 2012). In the context of the online advertising industry, for example, Goldfarb and Tucker (2010) show that strict European privacy laws reduce the effectiveness of online marketing by 65 per cent compared to the United States.

Web content and access restrictions can reduce incentives for innovation by limiting firms' understanding of consumer preferences and by limiting market size for providers of blocked content.[11] However, access restrictions to foreign websites or platforms can also serve to protect infant digital industries in a way equivalent to import bans (Erixon, Hindley and Lee-Makiyama, 2009). This can increase innovation and the performance of domestic firms offering the same service if the domestic market is sufficiently large. There is correlational evidence that suggests, for instance, that the Chinese firms WeChat and Baidu benefitted from the departure of foreign service providers like WhatsApp and Google (Chu, 2017; Vale, 2019). This is supported by Figure C.2, which shows that WeChat's active users in China increased above trend in the quarter in which WhatsApp left the Chinese market at the end of 2017. Restrictive data policies could also lead to retaliatory measures and may contribute to the fracturing of the internet, increasing the cost of conducting business globally (Swanson, Mozur and Zhong, 2020).

Data localization can have the effect of imposing costs primarily on foreign firms. Policies which require domestically acquired data to be stored locally can limit the data available to foreign firms, necessitate investment in domestic server capacity, and prevent data centralization. This can effectively protect domestic data-intensive industries and stimulate domestic innovation and performance. However, the limited evidence available to date suggests that data flow restrictions, such as data localization regulation, lead to lower levels of services traded over the internet and lower productivity, which hurts competitiveness. The negative effect is particularly strong for downstream firms which interact directly with consumers (Ferracane, Kren and van der Marel, 2020).

Based on case studies from Brazil, China, the European Union (28), India, Indonesia, the Republic of Korea and Viet Nam, data localization policies have also been shown to lead to substantial GDP losses, decreases in domestic investments and lower salaries (Bauer *et al.*, 2014). This supports the hypothesis that the free flow of information is conducive to firms innovating. When there are severe restrictions on the flow of information, individuals are prevented from collaborating and developing new ideas, in a manner similar to the effects of limits on goods, services or researcher mobility discussed above (Pepper, Garrity and LaSalle, 2016). Thus, data localization policies hinder the development of new information technologies which can benefit the ability of firms to innovate (Chander and Le, 2015).

**Figure C.2: WeChat's active user numbers increased with the departure of WhatsApp**
Quarterly active WeChat users in China (millions) (2017-18)




*Source:* https://www.statista.com/ based on Tencent annual reports.

Government data access policies are also central to innovation in the digital age. The public sector is one of the most important users and suppliers of data in the economy (OECD, 2015). "Open data" initiatives, which provide public data for non-commercial use for free, and for commercial use at prices below marginal costs, have strongly promoted the utilization of such data (see examples in section B2(c)). They are estimated to benefit product and sales growth significantly, with one study estimating that firms benefitting from access to open data experienced sales growth 15 per cent faster than other firms (Capgemini Consulting, 2013; Koski, 2011, 2015).

Privacy, security or other similar concerns, especially in sensitive areas such as the health or defence industries, can moreover lead to competitive advantages for domestic data-intensive firms if public data are made available based on nationality criteria or otherwise restricted such that only a subset of domestic firms can access it. This has an effect comparable to a production or innovation subsidy in the digital age, where firms rely on data (Goldfarb and Trefler, 2018). Of course, if access is too limited, this can generate market power and stymie domestic innovation and productivity rather than stimulate it. Evidence from US state medical privacy laws suggests, for instance, that variations in access to health records by hospitals contribute to explaining variations in neo-natal mortality (Miller and Tucker, 2011). More direct evidence for the importance and effects of public data access policies for innovation is not available, however, so a more precise assessment of these policies is currently not possible.

Overall, the available evidence generally promotes open and transparent data policies as important contributors to innovation in the digital age. While this evidence is limited so far, it broadly supports the idea that, for data to flourish as an input to innovation, it benefits from flowing freely. In light of the relative novelty of this field and the corresponding scarcity of studies, it is important to conduct more research on the relationship between data policies and innovation or firm performance to understand what the long term effects of such policies are, and to further substantiate the evidence that has been collected thus far.

## (b) Innovation funded by the government

It has been shown in Section B that governments worldwide employ various policies to support R&D. These policies find economic justification in the presence of market failures that prevent markets from supplying socially desirable levels of R&D (see Section C.2). Here, the focus is on the impact of tax incentives given to private firms performing R&D, on the impact of government research grants, on the role of government procurement, and on the role of government in "mission-oriented" innovation.

### *(i) Tax incentives for private R&D*

There is consensus in the economic literature that R&D tax credits increase R&D spending. In a recent survey, Becker (2015) concludes that the negative demand elasticity of R&D with respect to its own tax price is estimated to be broadly around unity. This implies that a 10 per cent fall in the tax price of R&D increases R&D by roughly 10 per cent. Subsequent studies (Dechezleprêtre *et al.*, 2016; Pless, 2019) find an even higher impact, with an estimated elasticity around 2.5.

Obviously, R&D tax incentives are meant to stimulate innovation. Firms, however, can respond to such incentives by relabelling other expenses as R&D to take advantage of favourable tax treatment (Chen *et al.*, 2018). To circumvent the issue of relabelling of non-R&D expenses as R&D expenses, some studies consider the direct impact of R&D tax credit schemes on non-R&D outcomes. Czarnitzki, Hanel and Rosa (2011) examine the effect of R&D tax credits on the innovation activities of Canadian manufacturing firms. Over the 1997-99 period, the Federal and Provincial R&D tax credit programmes were used by more than one-third of all manufacturing firms and by close to two-thirds of firms in high-technology sectors. Czarnitzki, Hanel and Rosa (2011) find that R&D tax credits increased the innovation output of the recipient firms. Tax credit recipients realized a higher number of product innovations and increased sales shares of new and improved products. The tax credit recipients were also more likely to introduce market novelties for both the Canadian (home) market and the world market.[12]

Using a rich database for Norwegian firms, Cappelen, Raknerud and Rybalka (2012) find that projects receiving tax credits result in the development of new production processes and to some extent the development of new products for the firm. However, the authors find no impact on innovations in the form of new products for the market or patenting. Bøler, Moxnes and Ulltveit-Moe (2015) find that the introduction of an R&D tax credit in Norway in 2002 stimulated not only R&D investments but also imports of intermediate goods. Finally, Dechezleprêtre *et al.* (2016) find that an R&D Tax Scheme in the United Kingdom induced a 60 per cent increase in patenting by "treated" MSMEs.[13] Taken together, the results of these studies provide some evidence that R&D tax credits can have an impact on innovation.[14]

Another concern with R&D tax credits is that they may not raise aggregate R&D, but rather may simply cause a relocation toward geographical areas with more generous fiscal incentives and away from geographical areas with less generous incentives (Akcigit and Stantcheva, forthcoming; Bloom, Van Reenen and Williams, 2019). There is evidence of such relocation both between sub-federal states in federal countries, such as the United States (see Moretti and Wilson, 2017), and internationally (see Akcigit, Baslandze and Stantcheva, 2016).[15] However, even in the presence of relocation effects, Bloom, Van Reenen and Williams (2019), conclude that "the aggregate effect of R&D tax credits at the national level both on the volume of R&D and on productivity is substantial".

Section B highlighted patent boxes as yet another fiscal instrument used by governments to spur innovation. Patent boxes are special tax regimes that apply a lower tax rate to revenues linked to patents relative to other commercial revenues (Bloom, Van Reenen and Williams, 2019). While, in theory, patent boxes may incentivize R&D, in practice they induce tax competition by encouraging firms to shift their intellectual property royalties into different tax jurisdictions (Bloom, Van Reenen and Williams, 2019; Neubig and Wunsch-Vincent, 2018). Using comprehensive data on patents filed at the European Patent Office, including information on ownership transfers pre- and post-grant, Gaessler, Hall and Haroff (2019) investigate the impact of the introduction of a patent box on international patent transfers, on the choice of ownership location, and on invention in the relevant country. They find some impact on patent ownership transfer, and no impact on innovation. This result, they conclude, "calls into question whether the patent box is an effective instrument for encouraging innovation in a country, rather than simply facilitating the shifting of corporate income to low tax jurisdictions".

### *(ii) Research grants*

With the amount they spend on R&D, countries can affect both the quantity and the quality of innovation. Shambaugh, Nunn and Portman (2017) report that countries with relatively low R&D spending tend to produce few high-quality patents (defined as those filed in at least two offices).

Several commentators have highlighted the active role of governments in shaping and fostering technological breakthroughs. Mazzucato (2013), for instance, argues that the US government is the economy's indispensable entrepreneur, innovating at the frontiers of science and technology, and able and willing to take risks in environments characterized by uncertainty about the end result of the innovation effort. Mazzucato (2013) uses the example of the technologies that currently make phones smart, such as the internet, wireless systems, global positioning, voice activation and touchscreen displays. All of these technologies, and others such as the search algorithm used by Google, were funded by the government through competitive research grants.

OPINION PIECE

**By Mariana Mazzucato,**
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# MISSION-ORIENTED INNOVATION AND INDUSTRIAL POLICY

The world faces enormous challenges around health and climate, and the underlying structure of our economies has prioritized short-term targets over long-term ones for too long. What is required is a radical change, consisting of putting challenges at the heart of the economy, rather than seeing economic growth on one side and the solutions to social problems on the other. With this aim, it is useful to think about the role of challenge-led policies – that is, policies that use investment and innovation to solve difficult problems (Mazzucato, Kattel and Ryan-Collins, 2019).[16]

Industrial strategies are seeing a revival around the world and should be harnessed to direct economies towards solving the biggest challenges through innovation and investment (Mazzucato, Kattel and Ryan-Collins, 2019; Mazzucato, 2018a). By creating well-defined missions to solve significant challenges, policymakers can influence the direction of growth by making strategic investments and using suitable policy instruments in many different sectors.

In order to apply innovation to challenges, the latter have to be broken down into ambitious but pragmatic and achievable tasks (Mazzucato, 2018b) or missions – concrete targets within a challenge, that act as frames and stimuli for innovation. Using missions to drive national industrial strategy or innovation policy means focusing less on sectors – such as the car industry, aerospace or telecommunications, as has been seen in past "vertical" policies – and more on the societal challenges that affect all.

One example of such a mission-oriented framework is the European Union's Horizon Europe research and development programme, in which a proportion of approximately € 100 billion will be deployed to five mission areas, as set out in my report for the European Commission, *Mission-Oriented Innovation Policy: Challenges and Opportunities* (Mazzucato, 2018b). In July 2019, I launched a second report titled *Governing Missions in the European Union,* which focused on three main areas: how citizens can be engaged in co-designing and co-implementing missions; what are the tools that the public sector needs in order to foster a dynamic innovation eco-system; and how can mission-oriented finance and funding leverage other forms of finance (Mazzucato, 2019).

The United Nations Sustainable Development Goals (SDGs) also present tremendous opportunities to direct innovation aimed at multiple social and technological challenges, thereby addressing the urgent need to create societies that are more just, inclusive and sustainable.

Today, in the midst of the COVID-19 crisis, the world must address the twin challenges of recovery from the economic shock due to COVID-19 and the transition to a low-carbon economy. These are not separate challenges. COVID-19 has prompted a bold state response, and if the green industrial strategy is to be successful, it will require a rethink on a similar scale of how governments negotiate with business. Strategies in which risks and rewards are shared fairly among all actors are vital for fostering the dynamic and sustainable investments that are needed across the long and uncertain process of innovation, and in order to produce a symbiotic, collaborative relationship between the public and private sectors.[17] The existing paradigm of socialized risks and privatized returns needs to be replaced by one where public investment leads to public returns.

If governments are fully to take this purposeful approach to innovation and industrial policy, they will need to learn how to build new types of public-private collaboration for the public good, and how this can be achieved through industrial policy. This must involve using tools such as procurement and patient strategic finance, but also truly confronting the "ways of doing things" that currently exist in government.

Governments can also have large impact on innovation through their procurement policies. Cozzi and Impullitti (2010) show that the technological content of government purchases is a *de facto* innovation policy instrument. Likewise, Moretti, Steinwender and Van Reenen (2019) argue that government defence spending is often the most important policy used by governments to affect the speed and direction of innovation in the economy.

This subsection evaluates the empirical evidence on the effectiveness of government research spending and procurement on innovation. It further considers the potential merits of "mission-based" innovation policy.

Governments may want to target specific types of R&D, for instance basic R&D rather than more applied R&D, if it is believed that they create more knowledge spill-overs than more applied R&D. Government research grants are a better instrument than R&D tax credits in these circumstances.

***University research and innovation***

Research grants awarded to academics significantly affect academic output, but also have the potential to affect private R&D, if the knowledge they help to generate spills over outside of the "ivory tower" of academia. High-technology firms often locate close to strong science-based universities. Such location choices are at least partly determined by geographically localized knowledge spill-overs from university research. Such spill-overs include personal interactions, university spin-off firms, consultancies and pools of highly trained graduates supplied by universities for employment in industry (Becker, 2015). Literature on the United States and a variety of other countries surveyed by Becker (2015) predominantly suggests that private R&D benefits from geographically localized knowledge spill-overs from university research.

More recently, Toivanen and Väänänen (2016) consider how universities affect innovation via their role as human capital producers. Using distance to a technical university in Finland as an instrument for engineering education, they find a large and significant impact of engineering education on patents: according to their estimations, establishing three new technical universities resulted in a 20 per cent increase in the number of United States Patent and Trademark Office (USPTO) patents by Finnish inventors.

A similar research question is studied by Andrews (2019), who estimates the causal impact on patenting of the (quasi random) allocation of universities to US counties over the period 1839-1954. He finds that establishing a new university resulted in 45 per cent more patents per year in that location than in runner-up locations (i.e. locations that were strongly considered to become the sites of new universities but were ultimately not chosen for exogenous reasons).

In a multi-country setting, Valero and Van Reenen (2019) show that a 10 per cent increase in a region's number of universities per capita is associated with 0.4 per cent higher future (five years ahead or more) GDP per capita in that region. They argue that the association of per capita GDP and the presence of a university works partly through the increase of the supply of human capital and partly by raising innovation.

Finally, Azoulay *et al.* (2019b), exploiting quasi-experimental variations in funding from the US National Institutes of Health (NIH) across research areas, show that a US$ 10 million increase in NIH funding to academics leads to 2.7 additional patents filed by private firms.

The literature discussed above clearly suggests that universities will continue to have an important role in fostering innovation in the digital economy.

***Publicly funded R&D conducted by private firms***

Government research grants are not only destined for academic researchers (or researchers in public labs or research centres), but also to private entities. The success of public R&D support of this form in stimulating private R&D depends on the design of the measure. Measures supporting firms' R&D that are transparent (e.g. research grants awarded through an open competitive process), non-discriminatory (equally available to domestic and foreign-established firms), and targeted towards young firms that face financing constraints in raising upfront capital, are more desirable than support measures for R&D that take the form of blanket subsidies benefiting large incumbents or domestic firms (OECD, 2019).

Evidence that direct R&D subsidy programmes can have positive impacts on innovation by small high-tech firms is provided by Howell (2017). She considers applications by such firms to the US Department of Energy's Small Business Innovation Research (SBIR) programme between 1983 and 2013 and finds that awards received in Phase 1 of the programme (which also had a Phase 2, for which successful Phase 1 applicants could apply nine months after receiving Phase 1 awards) have powerful effects. Phase 1 grants increase a firm's chance of receiving venture capital investment from 10 to 19 per cent. In addition, Phase 1 grants almost double the probability of positive revenue and increase the probability of the survival and successful market exit (initial public offering or acquisition) of small businesses. Most importantly for the purposes of this report, Phase 1 grants increase a firm's subsequent cite-weighted patents by at least 30 per cent.[18]

Although limited, there is also some evidence of a positive effect of public R&D subsidies on private R&D in some developing countries. For manufacturing firms in Turkey, Özçelik and Taymaz (2008) corroborate the evidence of additionality effects (i.e. public subsidies on average increase private R&D) found for several developing countries. More recently, Wu *et al.* (2020) show that R&D subsidies provided to 1,166 non-finance sector Chinese firms between 2008 and 2013 increased firms' innovation input (R&D investments), although they failed to foster innovation output (patent applications). Fernández-Sastre and Montalvo-Quizhpi (2019), using data on Ecuadorian firms for the period 2009-11, find that innovation support programmes which are intended to increase firms' technological capabilities induce firms to invest in R&D activities.

What is the combined effect of various policy instruments? This issue has received surprisingly little attention. Bérubé and Mohnen (2009), using data from the 2005 Survey of Innovation from Statistics Canada, consider the impact of R&D grants for Canadian plants that already benefit from R&D tax credits. They find that firms that benefited from both policy measures introduced more new products than their counterparts that had only benefited from R&D tax incentives. These firms also made more product innovations and were more successful in commercializing their innovations.

More recently, Pless (2019) tests whether direct grants and tax credits for R&D are complements or substitutes in their effects on UK firms' R&D investment behaviour. She finds that these schemes are complements for small firms but substitutes for larger firms on the intensive margin (i.e. increases in R&D expenditures by firms that already invest in R&D). She also shows that such complementarity between R&D policies enhances small firms' efforts towards developing new goods and services (i.e., horizontal innovations), as opposed to improving existing goods and services (i.e., vertical innovations), and that complementarity between R&D policies increases the probability that small firms will produce new or significantly improved goods, as opposed to processes.

### *(iii) The role of government as a customer of innovative products*

By enlarging the size of the market, public procurement in a given sector can spur private R&D and innovation. Examples abound – for instance, in the United States, the new technologies developed include semiconductors, large civil aircrafts, the internet and GPS technology, while digital phone switching technologies have been developed in Sweden and Finland, and high-speed trains have been developed in several countries.[19] Innovation in high-tech sectors, and in particular digital innovation, can therefore by increased by raising shares of government procurement in high-tech and digital sectors.

The innovation effects of public demand in the United States for the period 1999-2009 are investigated by Slavtchev and Wiederhold (2016). They relate state-level private R&D expenditures to the technological content of federal procurement in US states. Slavtchev and Wiederhold (2016) find that an increase in the technological content of government procurement induces additional private R&D in the economy.[20] The value of the elasticity of private R&D with respect to the high-tech procurement they estimate implies that each procurement dollar that the government shifts from non-high-tech industries to high-tech industries induces an additional US$ 0.21 of private R&D.[21]

Evidence that obtaining government contracts can spur dynamic learning effects is provided by Jaworski and Smyth (2018). Using data on all planes introduced in the commercial market between 1926 and 1965, they find that commercial airframe manufacturers with bomber contracts during the Second World War were more likely to have post-war market presence than firms without such contracts. They attribute the effect of bomber contracts to advantages in R&D learning capacity acquired by firms with military airframe contracts.

Cross-country evidence of the positive effects of government-funded R&D on private R&D is presented by Moretti, Steinwender and Van Reenen (2019). In a dataset comprising 26 industries in all OECD countries over 23 years, they find strong evidence that increases in government-funded R&D generated by variations in defence R&D translate into significant increases in privately funded R&D expenditures, with an estimated elasticity equal to 0.43.[22] This impact is economically sizeable. The authors consider the example of the US "aerospace products and parts" industry, where defence-related R&D amounted to US$ 3,026 million in 2002. Their estimates suggest that this public investment resulted in US$ 1,632 million of additional private investment in R&D. Moretti, Steinwender and Van Reenen (2019) further consider the impact of investment in R&D on productivity, finding a positive effect. An increase in defence R&D to the value-added ratio of one percentage point is estimated to cause a 5 per cent increase in the yearly growth rate of total factor productivity – i.e., from 2 per cent per annum to 2.1 per cent.

Overall, Moretti, Steinwender and Van Reenen (2019) show that cross-country differences in defence R&D play a role in explaining cross-country differences in private R&D investment, speed of innovation, and ultimately in the productivity of private-sector firms.

#### *(iv) The role of government in developing radical innovation*

Breakthrough technological developments are often achieved in the framework of mission-oriented innovation policies, which Bloom, Van Reenen and Williams (2019) call "moonshots" with reference to President J. F. Kennedy's Apollo programme.

Moonshots are characterized by a high level of centralization and intentionality (i.e. there is a specific and well-defined technology target) and heavy government intervention: the state is both the funder and the customer, and public agencies perform the R&D operations (École Polytechnique Fédérale de Lausanne (EPFL), 2020).

Moonshots are inherently hard to evaluate. This is due to the absence of clear counterfactuals (what would otherwise have happened had they not taken place) (Bloom, Van Reenen and Williams, 2019), but also to the fact that for a programme that makes long-term and high-risk investments, many failures can be justified by a single success. Furthermore, measurable short-terms outcomes such as publishing or patenting do not capture the success embodied in rare transformational outcomes (Azoulay *et al.*, 2019a).

Against this background, Bloom, Van Reenen and Williams (2019) discuss two main arguments that might justify moonshots.

First, the mission may be justifiable in and of itself. Bloom, Van Reenen and Williams (2019) give the example of using technology to address climate change. In this context, research subsidies have been shown to be prevalent in the optimal policy mix to mitigate climate change by transitioning from dirty to clean technology (Acemoglu *et al.*, 2012; 2016). A moonshot approach could speed up the pace of such a transition. Other desirable social goals, such as disease reduction, could also be the objective of a moonshot. In the context of the current COVID-19 pandemic, some have argued in favour of adopting "a mission-oriented approach that focuses both public and private investments on achieving a clearly defined common goal: developing an effective COVID-19 vaccine(s) that can be produced at global scale rapidly and made universally available for free" (Mazzucato and Torreele, 2020). This is discussed in Box C.4.

The second argument put forward by Bloom, Van Reenen and Williams (2019) that might justify moonshots is considerations related to geographical inequality. If moonshots are developed in cities or regions that lag behind in terms of economic development, the local spill-overs generated by them could spur the development of these locations.

### (c) Intellectual property protection

As discussed in WTO (2018a), the importance of IPR regulation is bound to increase in the digital age because many digital products are replicable at zero cost and are of a non-rival nature. This means that they can be consumed by an indefinite amount of people at the same time without a loss of utility. To ensure profitable prices for producers, strict and enforceable IPRs are central and can increase the attractiveness of a country for digital firms. WTO (2018) concluded, however, that whether IPR regulations increase or reduce competitiveness in digital sectors is ultimately an empirical question. On the one hand, weak copyright enforcement can lead to lower revenues in industries where copyrights matter, such as the music, film and publishing industries. On the other hand, tight IPR policies (such as, in the case of patents, longer patent terms, broader subject matter coverage or available scope, and improved enforcement) could constrain the creation and quality of digital products by limiting access or raising royalty costs.

In this subsection, the interest lies in the relationship between IPRs and innovation. In principle, stronger IPR protection should stimulate technology transfers to a country, while it has an ambiguous impact on domestic innovation (Hall, 2020). Empirical studies reviewed by Hall (2014) find a positive correlation between IPR enforcement and technology transfer through the channel of foreign direct investment (FDI), especially in host countries with enough absorptive capacity and ability to engage in imitation.

In terms of domestic innovation, empirical evidence is mixed. The direct effect of IPRs on growth is mediated by a number of factors, including a country's R&D capacity, its per capita wealth, the

**Box C.4: Is there a case for a mission-oriented approach in finding a vaccine for COVID-19?**

Finding a vaccine against COVID-19 is an "innovation imperative" (École Polytechnique Fédérale de Lausanne (EPFL), 2020), which seems to represent a strong case for a mission-oriented approach in which governments intervene in funding, developing and purchasing the new technology (i.e. the successful vaccine). Is this really the case?

In normal times, vaccines are subject to systematic underinvestment in R&D by private pharmaceutical companies for two fundamental reasons: first, there is not enough demand for vaccines; and second, R&D investment is subject to various market failures.

Too little demand for vaccines in normal times is due to the fact that there is a positive externality of being vaccinated (individuals who take vaccines not only become immune to the disease but also contribute to slowing down its transmission), to the fact that consumers seem to be more willing to pay for treatment than for prevention, and to the fact that some individuals are opposed to vaccination.[23]

On the supply side, R&D investment in vaccine development is discouraged by the gap between the social and the private returns to innovation, by the high risk in financing such activities, and by a time-inconsistency problem (once a vaccine is available, governments have incentives to obtain vaccines at prices that only cover manufacturing costs, but not R&D costs). Moreover, in the case of cross-border diseases, such as pandemic diseases, each country has an incentive to free ride on R&D financed by foreign governments (Kremer, 2000).

During the current pandemic, there has been a significant dissipation of most market failures for vaccine consumption (for instance, a significant fraction of consumers are willing to pay a higher price than the manufacturing cost) and market failures related to R&D (for instance, due to the research-encouragement effects of public-private partnerships). As a result, companies have worked with unprecedented speed to develop a vaccine. At the time of writing (early August 2020, a mere seven months after the first genome sequence of the SARS-CoV-2 virus was released), the landscape of COVID-19 candidate vaccines included six candidate vaccines in Phase 3 clinical stage (World Health Organization (WHO), 2020).

The current vaccine race is best described as the outcome of intellectual freedom, scientific openness and decentralized competition, rather than the outcome of a mission-oriented command-and-control approach.[24] This is not very different from past life science innovations. As argued by Cockburn, Stern and Zausner (2011), a single R&D surge seems never to have paid off in the pharma industry and has been actually counterproductive. Past and current experience therefore suggests that the current decentralized, competitive approach is preferable to a mission-oriented approach in the quest for a vaccine against COVID-19.

Once the vaccines are available, the important question of how to guarantee rapid, fair and equitable access to them. Advance market commitments – through which private or public donors pledge that, if a firm develops a specified new vaccine and sets the price close to the manufacturing cost, they will top up the price by a certain amount per dose – could play a role.[25] The manufacturer of one promising vaccine, AstraZeneca, has signed up to the Gavi Advance Market Commitment for COVID-19 Vaccines (Gavi COVAX AMC), launched in June 2020, guaranteeing 300 million doses of the COVID-19 vaccine it is developing in collaboration with the University of Oxford. These doses will be supplied upon licensure or WHO prequalification.

It should be noted that advance market commitments help with financing opportunities and alleviate the risks associated with vaccine production, but do not necessarily take into account an equitable allocation of vaccines. Together with guaranteeing a fixed amount of orders for the vaccine as an incentive for pharmaceutical firms, the Gavi COVAX Facility has further implemented an equitable distribution clause to ensure that no country is left behind in the pandemic, and that distribution of the vaccine is by necessity rather than demand.

nature and efficacy of its institutions, its development stage and its economic volatility (Gold, Morin and Shadeed, 2019). Cross-country studies that look at the correlation between IPR protection and innovation generally consider country-level measures of patents, without distinguishing between sectors/technologies. Exploiting the availability of patent data disaggregated by sectors, Figure C.3 displays a weakly positive (unconditional) correlation between IPR protection and the share of ICT patents in total patents in a cross-section of 91 developing and developed economies.[26]

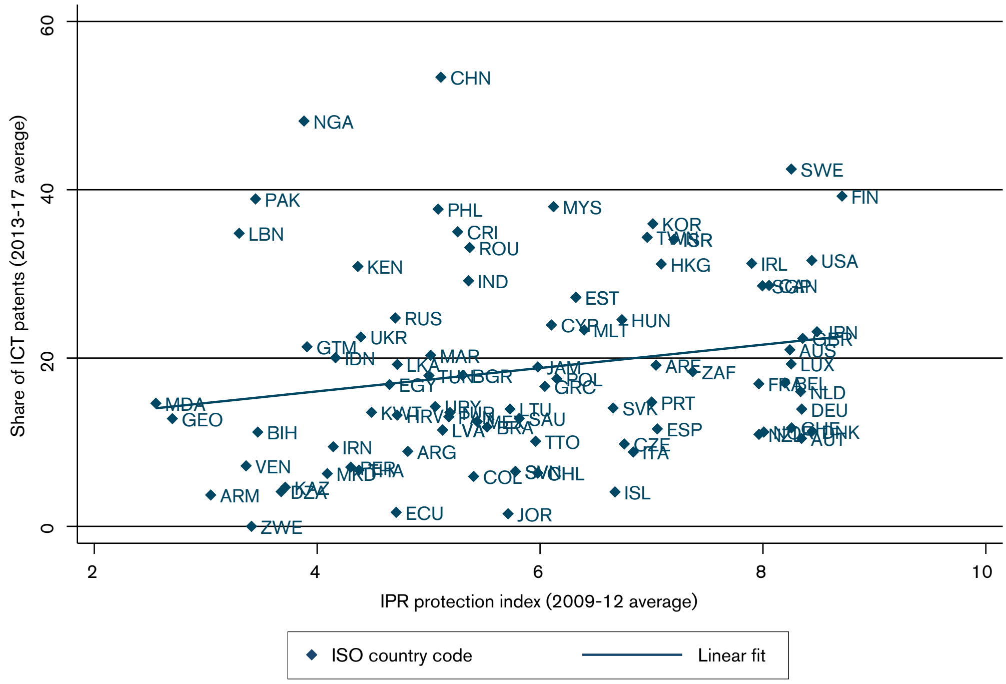
The question of whether IPRs have a causal impact on innovation can hardly be answered satisfactorily in cross-country studies, in the absence of exogenous variation in IPRs. A couple of recent careful studies show that patent protection increases the availability of new drugs.

Kyle and Qian (2014) consider the effect of pharmaceutical patent protection on (among others) the speed of drug launch in 60 countries from 2000 to 2013. They use variations in the compliance deadlines of the WTO Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS Agreement) at the product level to obtain exogenous variation in the "treatment" (i.e. the implementation of a minimum level of patent protection as mandated by the TRIPS Agreement). They find that patents have important consequences for access to new drugs: in the absence of a patent, launch is unlikely.[27] Cockburn, Lanjouw and Schankerman (2016) analyse the timing of the launches of 642 new drugs in 76 countries between 1983 and 2002. They show that longer and more extensive patent rights shorten the time span before new drugs become commercially available in different countries.

In a survey on the impact of patents on research investments, Williams (2017) identifies three key questions to be addressed. First, how does patent disclosure – i.e. the requirement to disclose the invention in exchange for the patent right – affect research investments? Second, is stronger patent protection – i.e. longer patent terms or broader patent scope – effective in inducing additional research

**Figure C.3: The share of ICT patents positively correlates with IPR protection**

Correlation between the share of ICT patents in total patents (2013-17 average, vertical axis) and the IPR protection index (2009-12 average, horizontal axis)




Coeff. = 1.388 (s.e. = 0.734)

*Source:* Authors' elaboration based on OECD patent data and the International Property Rights Index from Property Rights Alliance for property rights protection data.

*Notes:* The share of ICT patents is expressed as a percentage, as a share of patents in ICT sectors in total patents applications filed under the Patent Cooperation Treaty (PCT), by the inventor's country of residence.

investments? And third, do patents on existing technologies affect subsequent research investments?

For all these questions, the empirical evidence is not conclusive. There is limited evidence showing an increase in research investments due to patent disclosure.[28] There is also not much evidence that stronger patent rights encourage research investments.[29] And different studies come to different conclusions on the impact of IPRs on follow-on innovation.[30]

Compulsory licensing – under which a government allows the production of a patented product or process without the consent of the patent owner or plans to use the patent-protected invention itself – can be used to get access to essential foreign technology (a typical example being a life-saving drugs).[31] Such policy can impact innovation both in the licensing country and in the foreign country. The impact of compulsory licensing on invention in the licensing country is theoretically ambiguous (Moser, 2013). On the one hand, access to foreign-owned inventions may discourage domestic invention in the licensing country if it displaces domestic R&D. On the other hand, licensing may encourage domestic R&D that is complementary to foreign-owned inventions, increase the stock of knowledge and allow learning-by-doing. Empirically, Moser and Voena (2012) exploit an episode of extensive compulsory licensing under the US Trading with the Enemy Act (TWEA) of 1917 to identify its effects on patenting activity of US inventors in organic chemistry.[32] They show a 20 per cent increase in domestic patenting in response to compulsory licensing.

The effects of compulsory licensing in the country of the inventors whose patents were licensed are also theoretically ambiguous. Compulsory licensing may discourage long-run innovation by reducing the expected effectiveness of patents, but it may also foster innovation by increasing the threat of competition. The US TWEA made all German-owned patents available for licensing to US firms as of 1919. Baten, Bianchi and Moser (2017) study the impact of this episode of compulsory licensing on patenting activity by German firms. They show that German firms whose patents were licensed increased their R&D efforts in fields with licensing. On average, firms whose patents were licensed patented 89 per cent more after 1919 in fields with licensing.

Taken together, the case study results of Moser and Voena (2012) and Baten, Bianchi and Moser (2017) indicate a net positive cross-border impact of compulsory licensing on invention, both in the licensing country and in the country of the inventors whose patents are licensed. It is worth emphasizing, however, that these results refer to the exceptional case where an entire nation's patent portfolio is licensed within a wartime economy. Very little is known about the innovation impact of more limited forms of compulsory licensing that are more in line with current practice.

In the digital economy, IP protection takes the form of patents, trademarks and copyright, legal protection against the circumvention of technological protection measures or the removal of digital rights management information (see the discussion in Section D of WTO, 2018a) and, increasingly, trade secrets (Baker McKenzie, 2017). The complexity of products that use digital technology has led to the emergence of patent thickets, defined by Shapiro (2000) as a "dense web of overlapping IPR that a company must hack its way through in order to actually commercialize new technology". For instance, it is estimated that a smartphone is covered by 250,000 patents (Wagner, 2015). In theory, patent thickets may have the perverse effect of stifling innovation. However, in a sample of 121 publicly traded software firms during the period 1980-99, Noel and Schankerman (2013) find that greater fragmentation of patent rights is associated with lower market value, but higher levels of patenting and R&D.

Copyright law is more important in digital markets because digital products can be copied at zero cost (Goldfarb and Tucker, 2019). Several studies have addressed the issue of how copyrights affect the creation of new cultural products. The economic history literature suggests that copyrights increase the quality of creative output (Giorcelli and Moser, forthcoming). Evidence from the digital age, however, points in the opposite direction. Waldfogel (2012) shows that, while the quality of music began to decline in the early 1990s, it stopped declining, and may well have improved, in the decade following the 1999 arrival of free online copying. He explains this result by noting that digital technologies greatly reduced the costs of creating, promoting and distributing music. As a consequence, independent labels (whose releases represent a high share among albums most highly rated by critics) are playing a growing role in the music industry.[33] Similar results pointing to an increase in quality of cultural products in the digital era have also been found for books (Waldfogel and Reimers, 2015) and movies (Waldfogel, 2016).

Open source software (see Section C.2) is a digital public good for which IP protection serves the purpose of keeping the project non-excludable (Tirole, 2017). Consider the general public licence under which Linux operates. Users may freely copy, change and distribute it, but may not impose any restrictions on further distribution, and must make the source code available. That is, they are obliged to ensure that the community benefits from any modified version (Tirole, 2017).[34] Due to the non-rival and non-excludable nature of open source software, and to the immediate online availability of new code, high quality open source contributions can be widely adopted in a short time span.

There are many important contributions of open source software to digital innovation. As argued above in this subsection, data are a key input of digital innovation. With Big Data accumulating over time, data extraction and analysis methods based on AI require supercomputers, servers and cloud infrastructure. In 2019, all of the fastest 500 supercomputers in the world, 96.3 per cent of the world's top 1 million servers, and 90 per cent of all Cloud infrastructure were using the open source Linux operating system.[35]

### (d) Developing and attracting human capital

Human capital fosters economic growth through two mechanisms (Cinnirella and Streb, 2017). First, human capital can be viewed as a factor of production which increases productivity for a given level of technology – see for instance the contribution by Mankiw, Romer and Weil (1992), who present a production function where output is determined by physical capital, human capital and effective (i.e. technology-adjusted) labour. Second, human capital is an input in the innovation process – see for instance Romer's (1990) model of endogenous technological change. In this second mechanism, higher levels of human capital lead to the generation or diffusion of new technologies or to a more efficient adoption of a given technology, thereby shifting the production possibility frontier outwards.

Innovation is almost exclusively accomplished by formally educated individuals. Shambaugh, Nunn and Portman (2017) report that patent-holders are substantially more educated than the rest of the population: in the United States, 27 per cent of the population hold a Bachelor's degree, while more than 90 per cent of US patent-holders have at least a Bachelor's degree. The authors also show that high-quality patent activity (filing of the patent in at least two offices) is almost exclusively accomplished by people with advanced degrees. The percentage of triadic patent-holders (i.e. holder of a patent filed with all three of the United States, Japan and European Patent Offices) with a PhD, MD or equivalent degree is equal to 45 per cent, and 70 per cent of triadic patent-holders have at least a Master's degree. Only 23 per cent of them completed only a Bachelor's degree and – contrary to the stereotype of the college-dropout inventor/entrepreneur – only 7 per cent did not complete a four-year degree. Furthermore, the educational attainment of innovators has increased over time.

The type of human capital that seems to matter most for innovative activity (as measured by patenting) is STEM graduates (Romer, 2001). Shambaugh, Nunn and Portman (2017) report that industries that employ more STEM workers, such as communications equipment industries, produce more patents, even if some of the variation across industries is associated with differences in the tendencies of industries to use patents as the preferred mechanism to protect their IP. Autor *et al.* (forthcoming) show that this phenomenon is growing over time: the computer and electronics industries, which employ a large share of STEM workers, increased their patent production between 1975 and 2007. In contrast, the chemicals and pharmaceuticals industries, which have a much lower share of STEM employment, saw little or no growth in patenting.

In several countries there is a fear that the school systems do not produce an adequate number of STEM graduates to support innovation (Bianchi and Giorcelli, 2019).[36] In 2012, the US President's Council of the Advisors on Science and Technology (PCAST) highlighted the "need for approximately 1 million more STEM professionals than the United States will produce at the current rate over the next decade". This would be achieved by increasing "the number of students who receive undergraduate STEM degrees by about 34% annually over current rates".

Previous subsections discussed the role of universities as producers of the type of human capital that spurs innovation. Further insights can be gained from Bianchi and Giorcelli (2019). They exploit a 1961 reform that relaxed the enrolment requirements in Italian STEM majors, more than doubling the number of STEM first-year students, to document an increase in innovation activity, particularly in chemistry, medicine and information technology. The authors, however, also find that access to scientific educations increased employment opportunities in high-paid occupations not focusing on the production of patents.

This latter result is in line with Carnevale, Smith and Melton (2011), who argue (for the United States) that the increase in the relative demand for STEM workers (which was larger than the increase in their relative supply, leading to an increase in STEM workers relative wages) occurred across many sectors, including outside of STEM. In particular, Carnevale, Smith and Melton (2011) report that in all but two occupational clusters, the rate of growth in demand for core STEM competencies increased at far greater rates than the growth in employment. They conclude that "the growing demand for STEM talent allows and encourages the diversion of students and workers with STEM competencies".[37]

### *(i) The role of international migration*

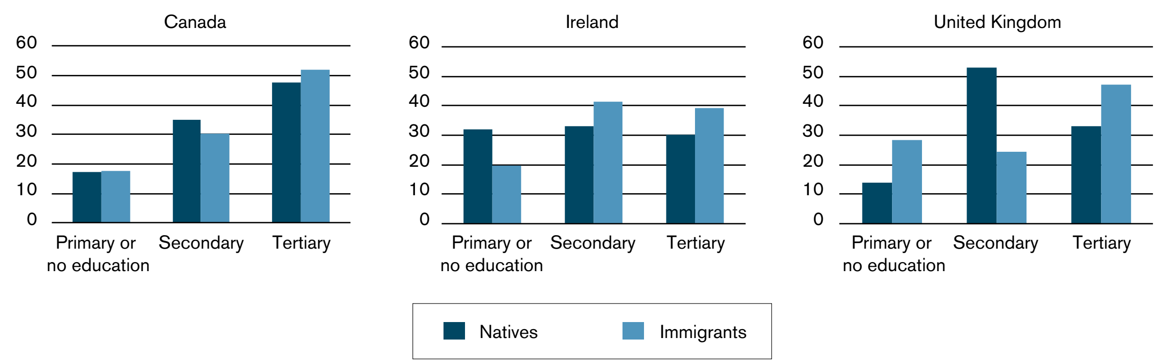
High-quality human capital can not only be produced domestically (through the education system), but also be imported (via permanent or semi-permanent immigration). The United States has traditionally constituted a magnet for talented immigrants. Shambaugh, Nunn and Portman (2017) report that while immigrants make up only 18 per cent of the US labour force aged 25 and older, they account for 26 per cent of the STEM workforce, for 28 per cent of high-quality patent-holders, and for 31 per cent of PhD holders. In other English-speaking countries such as Canada, Ireland and the United Kingdom, the share of immigrants with tertiary education is higher than the share of natives with tertiary education (see Figure C.4).

As shown in Figure C.5, in a cross-section of 63 developing and developed countries, there is an unconditional positive correlation between the country-level stock of highly-skilled migrants and the share of ICT patents in total patents. This suggests that highly skilled migrants positively contribute to innovation in the knowledge economy. The rest of this subsection discusses the empirical evidence available on the link between migration and innovation.

There is abundant research focusing on the extent of net innovation stemming from immigration of highly skilled migrants. Much like the evidence on the labour market effects of immigration, the evidence of the innovation effects of immigration is debated, at least for the United States. As reported by Kerr *et al.* (2016), studies exploiting long-horizon and spatial variation in high-skilled immigration often find results consistent with immigrants boosting innovation and productivity outcomes.[38] However, other studies suggest that immigrants mostly displace natives to yield a zero net benefit.[39] In the case of European countries, there is clearer evidence that national diversity has had a net positive impact on innovation.[40] The overall conclusions reached by Kerr *et al.* (2016) and by Bloom, Van Reenen and Williams (2019) is that highly skilled immigrants boost innovation and productivity.

Attracting highly skilled migrants to developed countries is generally implemented through one of two approaches. The first is a points-based system, which ranks individuals based on observable characteristics that comprise their skill set (education, language skills, work experience, existing employment). Australia and Canada implement such "supply-driven" systems. The second approach is an employer-driven system, in which firms select skilled workers for admission in the country. The US H1-B and L1 visas are primary examples of this "demand-driven" system.

**Figure C.4: In some countries, immigrants have higher educational attainments than natives**
Proportion of natives or immigrants with primary or no education, with secondary and with tertiary education, 2010 (immigrants) and 2011 (natives)

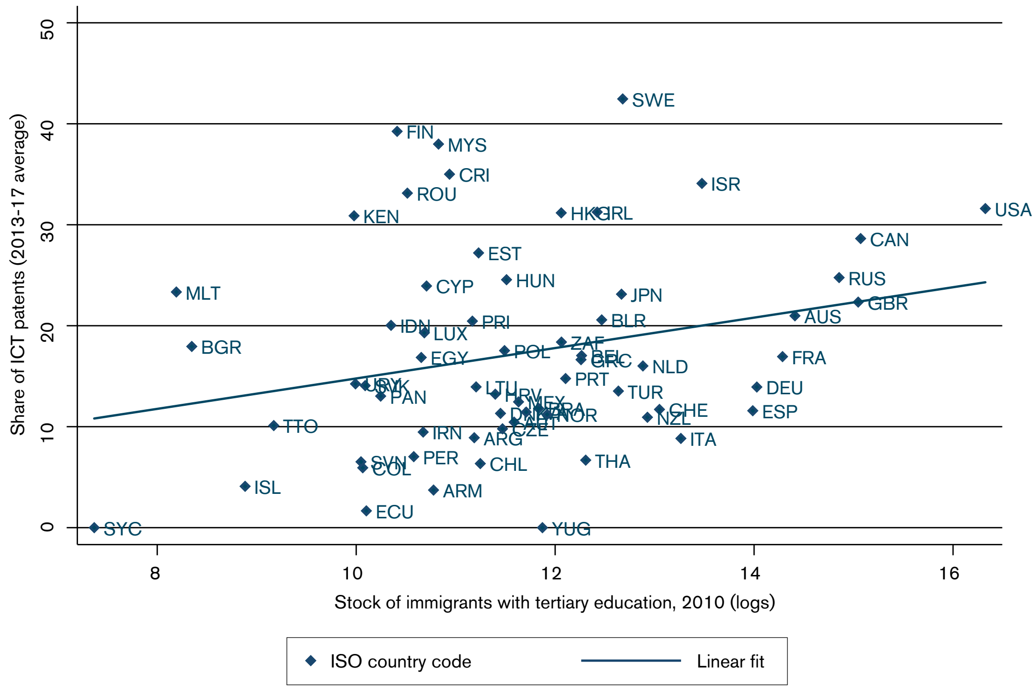



*Source:* Authors' elaboration based on data from OECD Database on Immigrants in OECD Countries (DIOC) for immigrants, and the United Nations Educational, Scientific and Cultural Organization (UNESCO) Institute for Statistics (UIS) for natives.

*Notes:* Primary or no education: International Standard Classification of Education (ISCED) 0-2. Secondary education: ISCED 3-4. Tertiary education: ISCED 5-6. Data are for the year 2010 round (which spans 2005-14) for immigrants, and for 2011 for natives. Data for immigrants are for individuals aged 15 or above. Data for natives are for individuals aged 25 or above.

**Figure C.5: The share of ICT patents positively correlates with the stock of highly skilled migrants**

Correlation between the share of ICT patents in total patents (2013-17 average, vertical axis) and the stock of immigrants with tertiary education (2010, in logs, horizontal axis)




Coeff. = 1.506 (s.e. = 0.632)

*Source:* Authors' elaboration based on OECD patent data and OECD Database on Immigrants in OECD Countries (DIOC) for immigrants.

*Notes:* The share of ICT patents is expressed as a percentage, as a share of patents in ICT sectors in total patents applications filed under the Patent Cooperation Treaty (PCT), and by the inventor's country of residence. Tertiary education: International Standard Classification of Education (ISCED) 5-6. Data on immigrants are for the year 2010 round (which spans 2005-14).

As discussed by Kerr *et al.* (2016), both systems have advantages and disadvantages, and in practice most immigration policies set by developed countries contain elements of both systems. Czaika and Parsons (2017) offer an empirical gravity-based evaluation, using annual bilateral (i.e. origin-destination) data on labour flows of highly skilled workers for ten OECD destinations between 2000 and 2012. They conclude that points-based systems are much more effective in attracting and selecting highly skilled migrants than systems which require a job offer, labour market tests and shortage lists. They also show that some provisions of bilateral agreements, such as the recognition of diplomas and social security agreements, also increase the skill composition of migrant flows.[41]

Using the 2003 National Survey of College Graduates, Hunt (2011) shows that immigrants who entered the United States on a student/trainee visa (e.g. F-1, J-1, H-3) or a temporary work visa (e.g. H-1B, L-1, J-1) have a large advantage over natives in patenting, commercializing or licensing patents, and writing books or papers for publication and presentation at conferences. Her results suggest a ranking of the gross contribution of immigrant groups according to their status on arrival in the United States: postdoctoral fellows and medical residents, graduate students, temporary work visa-holders, college students, other students/trainees, legal permanent residents, dependents of temporary visa-holders, and other temporary visa-holders.

Attracting highly skilled migrants is an important policy objective in several developing countries, too. The evidence on the impact of policies is, however, scant. In South-East Asia, for instance, there is some evidence showing a positive impact of skilled migrants on productivity in the Malaysian manufacturing sector, but no evidence that employing more skilled foreign workers has any effect on innovation or R&D spending in Thailand (see the studies discussed in Testaverde *et al.*, 2017). In Latin America, the Start-Up Chile programme pays foreign entrepreneurs to spend six months in the country in an effort to build global skill connections. The programme has been successful, as it supports between 200 and 250 new ventures per year, and Chile has launched other similar programmes (Kerr *et al.*, 2016). In an evaluation

OPINION PIECE

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# EDUCATION AND HEALTH AS INDUSTRIAL POLICY

Human capital is among the most important drivers of long-run economic growth and industrial development (Hanushek, 2013; Hanushek and Woessmann, 2011; Jones, 2014), yet it is frequently overlooked in discussions of industrial policy. As governments and business groups search for ways to boost economic growth, targeted measures often take precedence over basic investments in education and health. This is a mistake.

Economic growth is fuelled by people. An economy's capacity to produce is driven by the vitality, skills and innovation of its population. Without education, individuals have limited opportunities to imagine, create and build the products of today and the industries of the future. Without health, societies have neither the capacity to produce nor the appetite to consume the goods and services that form the backbone of industry. The COVID-19 crisis has demonstrated with unflinching severity the critical role of public health in the modern global economy. At the same time, the pandemic has highlighted the necessity for broad-based education, especially scientific literacy, as an essential determinant in countries' success in beating back the virus. No industry can thrive for long without the twin foundations of public education and health.

Education and health are not simply necessary preconditions for economic success. They are also critical drivers of frontier growth, particularly in high value-added, high-innovation sectors of the economy that depend on the cognitive skills and creativity of the working population (Ciccone and Papaioannou, 2009). In many such sectors, virtuous cycles can emerge: investments in human capital can increase a country's ability to compete globally in high-value industries. Growth in these industries expands the job opportunities and incentives for future educational and skill attainment by younger workers, who subsequently invest more in human capital, further deepening a country's competitive position in the future (Atkin, 2016; Bajona and Kehoe, 2010; Blanchard and Olney, 2017). Even small initial investments in human capital can yield significant economic returns over time.

Another important advantage of human capital investment is that it does not require governments to make risky gambles on future conditions in particular industries. It is notoriously difficult to "pick winners," and far too often, well-intentioned industrial policies end up betting on the wrong horse, wasting precious fiscal resources that, in hindsight, would have been better directed elsewhere. In contrast, investments in human capital strengthen a country's most important and flexible resource – its workers – who will naturally gravitate toward the most dynamic sectors, provided that labour markets are flexible and transparent, and that educational opportunity is broadly shared. Workforce flexibility also plays a critical role during hard times: healthier and more educated workers are more able to adapt to negative shocks and unexpected changes in the global economy. Economic resilience depends critically on workers' versatility, which depends in turn on individual health, public health, high-quality universal education and access to lifelong learning.

Finally, but most importantly, human capital investments are two-fers – "two for one" investments. Not only do investments in education and health boost economic growth, but they also contribute directly to individual and societal prosperity. The ultimate goal of economic development is to serve humanity. As key drivers not only of economic dynamism and resiliency, but also of the fundamental determinants of human progress, education and healthcare rank among the most vital and highest-return investments countries can make.

of special economic zones (SEZs) in Panama, Hausmann, Obach and Santos (2016) report that immigrants in Panama are more educated, more likely to be entrepreneurs, work in industries that are more complex and earn higher wages than nationals. They show large immigrant-to-national spill-overs in the form of a positive relationship between the share of immigrant employees and the productivity of Panamanian workers in a particular industry-province space. The authors conclude that Panamanian SEZs are functioning as channels that are not only moving people across borders, but are also transmitting know-how.

In developing countries, innovation and its diffusion are more likely to be impacted by the emigration than by the immigration of highly skilled individuals. Diasporas can generate net positive gains for the migrants' home countries (see Docquier and Rapoport, 2012; Parsons and Winters, 2014 for extensive reviews). Box C.5 discusses, in particular, how diasporas can impact innovation in the emigrants' countries of origin.

### (e) Regulation of competition

Some economists have posited an inverse U-shaped relationship between competition and innovation (Aghion *et al.*, 2005). In their framework, at low initial levels of competition, more competition would foster innovation, while at high initial levels of competition, more competition would hinder innovation.

Recent empirical research shows, however, that if there is an effect of competition on innovation, it is a positive one.[42] Federico, Morton and Shapiro (2020) contend that the notion of an inverse U-shaped relationship between competition and innovation is not only empirically, but also theoretically invalid. They argue that greater rivalry, in the sense of greater contestability of future sales, unambiguously leads to more innovation. This is because in contestable markets, future sales will be won by the most innovative firm – be that the incumbent or a disruptive challenger. Therefore, both current market leaders (including a dominant incumbent) and disruptive rivals have an incentive to innovate and capture future sales in contestable markets. It follows that innovation-friendly competition policy prevents "current market leaders from using their market power to disable disruptive threats, either by acquiring would-be disruptive rivals or by using anti-competitive tactics to exclude them" (Federico, Morton and Shapiro, 2020).

The evidence of the impact on regulation of competition on innovation is quite sparse, although generally supportive of a positive effect.

First, some studies have shown, both for developing and developed countries, that product or service market regulation reduces the intensity or the efficiency of R&D in the same sector or in downstream sectors.[43]

Second, there is some evidence that competition law enforcement may enhance innovation. Koch, Rafiquzzaman and Rao (2004) find positive impacts of antitrust regulation on the R&D intensity in former G7 countries. Büthe and Cheng (2017) find that the effect of a country having a substantively meaningful competition law on innovation (measured by the number of patent applications) is positive in cross-sectional and panel analyses for OECD and developing countries. More convincingly, Watzinger *et al.* (forthcoming) consider the potential impact of compulsory licensing as an antitrust remedy to increase innovation.[44] They exploit a 1956 consent decree which settled an antitrust lawsuit against Bell (a US telecommunications equipment firm), forcing Bell to license all its existing patents royalty-free, including those not related to telecommunications. Watzinger *et al.* (forthcoming) show that this led to a long-lasting increase in innovation, but only in markets outside the telecommunications industry. Conversely, no effect is found within telecommunications, where Bell continued to exclude competitors. This is evidence that compulsory licensing can act an effective antitrust remedy if markets are contestable.

Third, several studies show that the removal of market entry barriers fosters innovation. In the pharmaceutical sector, Grossmann (2013) finds that entry deregulation increases firms' R&D intensity. In the digital technology field, Gruber and Koutroumpis (2013) consider the effect of regulatory policy changes that introduced retail local loop unbundling (LLU) – a form of technology that allows multiple providers to use a single telecom network. In a sample of 167 developing and developed countries during the period between 2000 and 2010, they provide evidence that full LLU and, to an even larger extent, retail LLU positively affect the adoption of broadband telecommunications.

Similarly, Nardotto, Valletti and Verboven (2015) consider the impact of regulation on broadband infrastructure on broadband penetration in the United Kingdom. They document a strong – although heterogeneous across locations – increase in LLU entry in the United Kingdom over the period between 2005 and 2009. During the same period, broadband penetration more than doubled. LLU entry only contributed to higher penetration levels in the early years of the sample, while inter-platform competition (from cable) positively contributed in all years of the

**Box C.5: Diasporas, brain circulation and innovation in migrant origin countries**

The emigration of scientists and engineers has long been regarded as a threat to the innovation potential of their countries of origin through the loss of home-educated human capital or "brain drain". Several strands of research discuss various compensatory mechanisms through which innovation may take place in or diffuse to migrant countries of origin due to the "circular flow of talents" (also known as "brain circulation").

First, networks of inventors from the same country may have a role in spurring innovation diffusion in their country of origin. Kerr (2008) finds that non-US based researchers tend to cite US-based researchers from their own countries 30-50 per cent more frequently than US-based researchers from other countries. This is consistent with a positive role of "frontier expatriates" in the adaptation of foreign frontier technology to local production.

Agrawal *et al.* (2011), however, reach different conclusions. They show that the likelihood that a patent is cited by Indian inventors is more likely influenced by co-location effects (i.e. the fact that at least one of the inventors of the cited patent is in India) than by diaspora effects (i.e. the fact that at least one of the inventors of the cited patent is an Indian located abroad). They conclude that – except in the case of high-value inventions – technology absorption might be higher if highly skilled workers stayed at home than if they migrated.

In a similar vein, Breschi, Lissoni and Miguélez (2017) show that "brain gain" effects (US-resident foreign-origin inventors being disproportionally cited by inventors in their home countries) exist for China and Russia, but not for India.

Second, migrant inventors may facilitate the conduct of innovative activity (R&D and patenting) in their countries of origin. As shown by Kerr and Kerr (2018), between 1982 and 2004, the share of R&D for US companies conducted by their foreign operations rose from 6 per cent to 14 per cent (see also Branstetter, Li and Veloso, 2014). During the same period, patents with global inventor teams (i.e. patents where at least one inventor is located outside of the United States and at least one inventor is located within the United States) rose from 1 per cent of US public firm patents in 1982 to 6 per cent in 2004.

Miguélez (2018) documents the role of highly skilled diaspora communities for the development of global inventor teams. He finds that international collaboration in patenting activities within pairs of developing-developed countries is positively correlated with the stock of migrant inventors from one country into the other. Foley and Kerr (2013) study the impact that non-US born innovators have on the operations of the foreign affiliates of US MNCs. They find that increases in the share of a firm's innovation performed by inventors from a particular country are associated with increases in investment and innovation in those inventors' countries, and with decreases in joint venturing with local companies.

Third, returned migrants may have an important role to play in innovation back home. Liu *et al.* (2010) exploit a four-year panel dataset of around 1,300 enterprises located in the Zhongguancun Science Park (Beijing, China). Both ownership by a returnee and the density of returnees in the company's sector positively affect patenting activity, measured by the number of patents filed by each firm at SINO (the Chinese patent office). Similarly, in a sample of more than 800 Chinese photovoltaic firms between 1998 and 2008, Luo, Lovely and Popp (2017) show that corporate leaders who have studied or trained in an advanced country positively influence patenting activity. Research also shows that Chinese returnee entrepreneurs play a positive role in promoting innovation by firms that are geographically close to the firm where they are employed (Filatotchev *et al.*, 2011; Luo, Lovely and Popp, 2017).

In the case of India, Nanda and Khanna (2010) find that entrepreneurs who were members of the National Association of Software and Services Companies trade association and who had previously lived outside of India were more likely to activate overseas connections when living outside of the prominent software hubs. Choudhury (2016) studies whether return migrants facilitate knowledge production by local employees working for them at geographically distant locations. Using data for 1,315 employees at the Indian R&D centre of a technology firm, he finds that local employees with returnee managers file more US patents than local employees with local managers.

**Box C.5: Diasporas, brain circulation and innovation in migrant origin countries *(continued)***

In countries with very high "brain drain" rates, however, the impact of return migrants on innovation creation or diffusion is modest at best. Using survey data for Tonga, the Federated States of Micronesia, Papua New Guinea, Ghana and New Zealand (countries with high "brain drain" rates in their respective geographical or income group), Gibson and McKenzie (2012) find that returned migrants are only marginally more likely to engage in knowledge transfer than non-migrants, especially to business.

Overall, there is evidence that migration is an important factor in innovation creation and diffusion in most migrants' countries of origin. However, as emphasized by Carlino and Kerr (2015) and Kerr *et al.* (2017), more research is needed to understand the relative impact of different forms of migration, including permanent migration to the new economy, regular business travel across places (which, looking at U.S. business travel to foreign countries, Hovhannisyan and Keller, 2014 show to have a positive impact on innovation in these countries) or return migration.

sample. However, local markets that experienced LLU entry had a considerably higher average broadband (a measure of quality of service) speed than those that did not experience LLU entry.

Finally, Molnar and Savage (2017) show that, in the United States, internet wireline speeds are often higher in markets with two or more wireline internet service providers (ISPs) than with a single wireline ISP.

For countries in the process of development, market entry barriers are relatively less harmful the further away the country is from the world technology frontier (Acemoglu, Aghion and Zilibotti, 2006). This is because the adoption and adaptation of existing technologies does not require as tough a selection of high-quality entrepreneurs as that required for frontier innovation. Moreover, a would-be pioneer entrepreneur in a developing country interested in adapting an existing foreign technology to the local market, i.e. self-discovery, may have more incentives to innovate in the presence of market entry barriers than in their absence.

These arguments come with an important caveat. Government intervention in the form of policies limiting product market competition, among others, may only be useful to improve the short-run allocation of resources, but may have adverse long-run consequences, including making the economy stick in a non-convergence trap, from where it fails ever to achieve the world technology frontier (Acemoglu, Aghion and Zilibotti, 2006).

### (f) Creating an innovation-friendly environment

This subsection considers a set of policies that contribute to creating an innovation-friendly environment. First is an examination of policy aimed at building and maintaining telecommunication infrastructure. Such policy is crucially important for innovation, and in particular digital innovation, because access to broadband is an essential input in the innovation production function. Second, the impact of policies favouring agglomeration of economic activity is reviewed. Third, policies that favour the exposure to innovation during childhood are discussed, as well as why such policies are likely to have a large impact on innovation, by allowing talented individuals to become inventors, even if they are born into disadvantaged socio-economic groups.

#### *(i) Telecommunication infrastructure policy*

ICTs contribute significantly to economic and productivity growth and efficiency (Sharafat and Lehr, 2017). Access to a reliable, comprehensive and affordable high-speed broadband network is essential for such contributions to materialize, and it is likely to become a central factor of competitiveness in the digital age, as discussed in WTO (2018a). Yi (2013) finds for 21 OECD countries that better broadband access provides for a comparative advantage in less routine task-intensive sectors. The production of innovation, and in particular digital innovation, is by its very nature intensive in non-routine tasks. Indeed, high-speed broadband is an essential input in the digital innovation production process. Consequently, only countries (or locations within countries) endowed with a reliable, comprehensive and affordable high-speed broadband network will be able to contribute to innovation, especially in the digital realm.

#### *(ii) Policies to favour agglomeration*

Innovative activity, including R&D, venture capital investments and patents, is spatially concentrated (Carlino and Kerr, 2015). The spatial concentration of innovative activity is largely driven by the same forces that determine the spatial concentration of economic activity (see Box B.2): sharing of common inputs, matching in local labour markets and knowledge spill-overs.[45] According to Madaleno *et al.* (2018), sharing effects arise from pooled equipment, facilities, etc.; matching effects from networking or peer-to-peer linkages, which help to identify partners; and knowledge spill-overs arise from peer-to-peer interactions, mentoring or networking. On the negative side, there can also be diseconomies of agglomeration, for instance if knowledge spill-overs give rise to group thinking and the poaching of ideas in environments where secrecy may be hard to maintain (Madaleno *et al.*, 2018). The net effect on innovation is positive, however, as shown by the fact that innovative activity is significantly more concentrated than general economic activity.

In knowledge-based economies, "tech clusters" (Kerr and Robert-Nicoud, 2019) or "science parks" (Liang *et al.*, 2019) play a growing role in accommodating high-tech firms. In the absence of targeted policy interventions, such clusters emerge as an equilibrium outcome when there are strong localized knowledge spill-overs, high start-up costs, skilled labour abundance, or low commuting costs (Liang *et al.*, 2019). Furthermore, location-specific endowments of fixed factors in the production of innovation, such as strong universities and government-sponsored laboratories, are important attractors of clusters of innovation. Historical accidents (including where breakthrough inventions were made, or where anchor firms initially locate) and self-fulfilling expectations (Krugman, 1991) also matter.[46]

Co-location policies aimed at encouraging high-tech firms to locate in high density accelerators, incubators or science parks are increasingly popular.[47] There is, however, little empirical evidence that justifies such policies. Chatterji, Glaeser and Kerr (2014) note that, among the three most well-known clusters in the United States (Silicon Valley, Boston's Route 128, and Research Triangle Park), only the latter was clearly a product of dedicated state-level planning. Hochberg (2016) documents a few empirical attempts to assess whether US accelerators do indeed have a positive effect on the outcomes of the companies that participate in the programmes, with mixed results. Gonzalez-Uribe and Leatherbee (2017) consider the impact of Start-Up Chile, an accelerator aimed at stimulating start-up activity by offering equity-free cash infusion, shared co-working office space and the possibility of being selected into an exclusive sub-programme, akin to an "entrepreneurial school". They find no evidence that basic accelerator services of cash and co-working space have an effect on the fundraising, scale or survival of treated start-ups.

Conversely, the combination of basic accelerator services and entrepreneurship schooling leads to significantly higher venture fundraising and scale (number of employees). For the United States, there is evidence that accelerator programmes have a positive impact on the region (regardless of their effects on the small number of companies that attend them): US metropolitan statistical areas that receive an accelerator programme exhibit significant differences in initial (seed and early stage) venture capital attraction compared to areas that do not receive an accelerator programme (Fehder and Hochberg, 2014).

In the case of science parks, there is some evidence of a direct impact on innovation. In particular, two studies reviewed by Madaleno *et al.* (2018) find that co-location in science parks increases patenting both within and across industries for firms in the park. United Nations Conference on Trade and Development (UNCTAD) (2019) further reports that, in the 156 high-tech development zones established in China by the end of 2017, the ratio of R&D expenditures to total production value was 6.5 per cent, three times the average in the national economy. Patents granted to enterprises within such high-tech development zones account for 46 per cent of all business patents granted nationwide.

The experience of Chinese high-tech development zones suggests that SEZs might play a role in supporting innovation in the digital economy. At present, however, there is no systematic evidence of the impact of SEZs on innovation, let alone in digital sectors.

### *(iii) Policies to favour individual exposure to innovation*

Most talented people never become inventors in the first place, for reasons that have to do with the environments in which they grow up. Bell *et al.* (2019) show that, in the United States, children born into low-income families, women and minorities are much less likely to become successful inventors. They provide evidence that gaps in innovation across individuals with different characteristics at birth are not due to inherited differences in talents or preferences to pursue innovation as a career. Rather, they are driven by differences in exposure to innovation during childhood through one's family or neighbourhood. According to Bell *et al.* (2019), increasing exposure to innovation among children who excel in mathematics and science at early ages, but come from unrepresented groups, can have large effects on aggregate innovation. They estimate that if women, minorities and children from lower-income families were to invent at the same rate as white men from high-income (i.e. top-quintile) families, the total number of inventors in the US economy would quadruple.

The results of Bell *et al.* (2019) suggest a potentially large innovation impact of policies to increase exposure to innovation. Such policies, they argue, could range from mentoring by current inventors to internship programmes at local companies. Since it is talented children born in low-income families, women, and minorities that are relatively more likely to be "lost Einsteins", Bell *et al.* (2019) further suggest that aiming exposure programmes at women, minorities and children from low-income families who excel in maths and science at early ages is likely to maximize their impacts on innovation.

### (g) Aggregate impact of innovation policy

Most empirical literature on the determinants of innovation does not deal with the aggregate effects of innovation policy. As argued above, in estimating the impact of some innovation policies, like R&D tax credits, it should be considered that these policies may simply cause a relocation toward geographical areas with more generous fiscal incentives and away from geographical areas with less generous incentives. Such relocation might both occur within borders and across borders – a point further elaborated in Section C.4.

There are relatively few studies that address the impact of innovation policy on aggregate welfare. Sollaci (2020) investigates the impact of the spatial dispersion of R&D tax credits in the United States. Increasing the geographical concentration of innovation in highly productive locations on the one hand increases the rate of growth of the economy, and on the other hand reduces individual firms' investments in R&D due to a higher rate of creative destruction (i.e. faster product and process innovation by which new products and processes replace outdated ones). Empirically, Sollaci (2020) finds that removing the spatial variation of R&D tax credits in the United States would generate a reduction in welfare, implying that the US states that offer the largest credits are indeed those that are comparatively better at producing innovation. However, he also finds that welfare could be further improved through an optimal distribution of R&D tax credits.

Knowledge spill-overs are critical in shaping the aggregate welfare impact of innovation policy. Atkeson and Burstein (2019) consider that changes in the innovation intensity of the economy entail relatively modest annual fiscal costs in the long run, equal to 1.1 per cent of GDP. Depending on the calibration, the corresponding changes in welfare range from 1.7 to 20 per cent of aggregate consumption. The lower bound (1.7 per cent) is obtained in a scenario with business-stealing (i.e. the entry of a lower-cost alternative makes incumbent firms cease production of a product) and with low intertemporal knowledge spill-overs (i.e. knowledge spill-overs that occur over time); the upper bound (20 per cent) is obtained in a scenario without business-stealing and with high intertemporal knowledge spill-overs. Note that, even assuming that business-stealing occurs, innovation policy entailing annual fiscal costs in the long run of 1.1 per cent of GDP would increase welfare by 7.3 per cent, with high intertemporal knowledge spill-overs. These results show, once again, the importance of knowledge spill-overs stemming from innovation (for similar conclusions, see also Atkeson, Burstein and Chatzikonstantinou, 2019).

Beyond aggregate welfare impacts, another important question to be addressed in evaluating the aggregate effects of innovation policy is how and whether it affects inequality within a country.[48]

As extensively discussed in WTO (2017a), technological progress can be biased in favour of certain groups of workers depending on their skills or on the tasks they perform. Digital innovation is a typical example of skill-biased technical change, because digital technologies tend to be used more intensively by skilled workers than by unskilled workers. Moreover, digital innovation tends to be routine-biased since it decreases the relative demand for routine tasks.

In general, workers performing non-routing cognitive tasks tend to see both their employment opportunities and their earning go up; workers performing routine tasks (both manual and cognitive) tend to see both their employment opportunities and their earnings go down; and workers performing non-routine manual tasks tend to see their employment opportunities go up, but their earnings go down as middle-skilled workers in routine occupations are displaced and start competing for the available jobs in non-routine manual occupations (WTO, 2017a). The resulting employment and wage polarization in labour markets is a source of inequality that can be (at least partly) driven by digital innovation.

Furthermore, it has been argued in several parts of this report that when there are network externalities and technology lock-ins, "winner-takes-all" dynamics are likely to emerge. Innovation-based rents, while needed to incentivize innovation and compensate for its cost, tend to accrue mainly to investors and top managers and less to the average workers, thereby increasing income inequality (Guellec and Paunov, 2017). Consistently with this, Aghion *et al.* (2019a) find that, across US states and local labour markets, there is a positive impact of innovation on top income inequality. Innovation does not, however, increase broad inequality. This is because innovation, particularly by new entrants, is positively associated with social mobility.[49]

In contrast, lobbying to prevent entry by an outside innovator dampens both the impact of entrant innovation on top income inequality and the impact of innovation on social mobility. Based on these results, Aghion *et al.* (2019a) conjecture that, unlike innovation, lobbying should be positively correlated with broad measures of inequality, and negatively correlated with social mobility. This points once more to the importance, not only for innovation, but also for preventing further rises in inequality, of the above-discussed regulations of competition that ensure that current market leaders do not prevent entry of disruptive rivals via preventive takeovers or other anti-competitive tactics.

## 4. Cross-border effects of innovation policies

One important aspect of innovation policies in the context of trade is that they often have an impact on other countries. These spill-over effects are partly based on the same factors that provide an economic rationale for innovation policy, ranging from knowledge spill-overs to inter-industry linkages, but there are also additional externalities such as competition for scarce resources.

This subsection reviews the main cross-border effects of innovation (sections C.4(a) to C.4(e)) before analysing potential changes to these externalities arising in the digital age (Section C.4(f)). It concludes with a discussion of the potential aggregate cross-border effects of innovation policy and how policy can be designed to minimize negative spill-overs to other countries (Section C.4(g)).

A key message of this chapter is that cross-border externalities can be both positive and negative. For instance, knowledge created in one country tends to benefit other countries as it diffuses across space over time. On the other hand, innovation incentives can attract human and physical capital from one country to another, and this can hurt innovation in the former.

It is also important to highlight that cross-border externalities can be caused to varying degrees by almost all policy tools discussed in this report, from trade policy to tax policy or even education policy. Understanding which policy tools maximize positive spill-overs and minimize negative spill-overs is crucial to designing innovation policy well. This brings us to the final key message, which is that the absence of high-quality literature in this area makes policy advice difficult and emphasizes the need for future research.

### (a) Knowledge spill-overs and technology diffusion

Two of the most analysed cross-border externalities are knowledge spill-overs and technology diffusion. Endogenous growth theory argues that innovation is not just based on private inputs to the innovation process but also on the stock of publicly accessible knowledge which has been generated through previous R&D investments across the world (Grossman and Helpman, 1991; Romer, 1990). It is the formalization of the well-known concept of "standing on the shoulders of giants".

The idea is that once an innovation has been made, it can inspire and accelerate follow-up innovations. As a result, innovation policy pursued by one country can benefit the innovation activity of all other countries, since it increases the global stock of knowledge. In addition, innovation policy has spill-over effects, by creating technology that diffuses globally and facilitates the technological catch up and innovation of countries that are not at the technology frontier. There is a large literature confirming this theory, and the presence of international knowledge spill-overs that goes back to Coe and Helpman (1995). This literature has been further discussed in Section C.3(a).

A related strand of literature discusses other types of regional spill-overs and agglomeration effects of industrial and innovation policy. Such effects comprise, for example, labour-pooling when policy attracts skilled workers to a region, or local demand and supply linkages when policy causes suppliers and customers of targeted industries to locate in the targeted region. There is, for instance, evidence that capital subsidies, such as investment grants, benefit regional investment and employment but not productivity (Cerqua and Pellegrini, 2017). For SEZs, positive regional spill-overs, including increases in productivity and human capital investments, have also been found for neighbouring regions and cities further away (Alder, Shao and Zilibotti, 2016).

While this literature looks mostly at domestic regional spill-overs, the findings are also relevant for cross-border externalities, as many economic regions extend beyond national borders such as the Great

Lakes Regions in Africa (Burundi, the Democratic Republic of the Congo, Kenya, Malawi, Rwanda, Tanzania and Uganda) and North America (United States and Canada). More generally, regional spill-overs are always likely to affect neighbouring countries if they are targeted at regions close to the border in the intervening country.

## (b) Strategic government policy

A second well-studied cross-border externality arises in the context of imperfectly competitive markets, such as oligopolies. If markets are not perfectly competitive, firms can extract rents or profits. That is, they can set prices above marginal costs. If only a few firms from different countries operate in a market, these firms share these rents. In such a situation, different policy tools, such as subsidies or tariffs, can shift rents from a producer in one country to a producer in another, or allow for increased entry in the intervening country. This is typically referred to as strategic trade policy and provides another theoretical underpinning for infant industry protection.

The idea behind strategic trade policy is that firms set their output or prices strategically, taking into account the output or prices of their foreign competitors. Countries can limit foreign firms' sales or boost the domestic firm's sales through different tools from export or R&D subsidies to import tariffs. The mechanism is that the policy intervention allows the domestic firm to enter the market or to lower its price and increase output. This, in turn, causes the foreign firms to strategically limit their output to protect their profit margin. Effectively, the policy intervention shifts the profits from these new or additional domestic sales from foreign to domestic producers and thereby raises domestic welfare at the expense of foreign welfare (Brander and Spencer, 1985; Spencer and Brander, 1983).

Applications of strategic trade policy have been observed in various contexts. Prominent examples include the market for large civil aircraft (Baldwin and Flam, 1989; Baldwin and Krugman, 1988), the automobile market in connection with voluntary export constraints (Krishna, Hogan and Swagel, 1994; Venables, 1994) or the semiconductor market (Baldwin and Krugman, 1986). Results of such simulation exercises often vary widely depending on parameter choices, but they typically differ from the majority of trade models in that they advocate some form of trade policy intervention over free trade. However, in many of these analyses, alternative policy tools, such as production subsidies, are preferable since they imply less costs for consumers (Brander, 1995).

## (c) Competition for scarce resources

A related cross-border externality arises through competition for scarce resources or factors of production. If innovation policy attracts those factors of production, be they human capital, investment or any other resource, this can severely limit the supply of these factors in other countries. Similarly, if a policy prevents these resources from being exported, it limits availability abroad. This effect is particularly strong for very rare production factors. There is, for instance, evidence that tax policies are important to attract inventors with the most highly cited patents. Estimates suggest an elasticity of 1 for such foreign "superstar" investors with respect to the top marginal income tax rates (Akcigit, Baslandze and Stantcheva, 2016).

The same is likely to apply to data where data localization policies in different countries can act as a barrier to innovation for firms operating in these countries as they cannot connect data across borders. This, in turn, reduces innovation in the firms' headquarter countries (Pepper, Garrity and LaSalle, 2016).

Tax incentives that attract company headquarters or research facilities are likely to have the same effect and can, in addition, impose harm on the domestic economy if such incentives are too generous (Bartik, 2018; OECD, 1998). While focusing on domestic cross-state tax competition, one study has found, for example, that state-level R&D tax credits in the United States spurred local innovations, but largely by shifting R&D expenditure away from other US states, leading to "beggar-thy-neighbour" effects (Wilson, 2009). This type of cross-border externality has recently also been in the spotlight due to the discussion surrounding the incentives offered by various US states to Amazon for its second headquarters (Parilla, 2017).

## (d) Supply-and-demand effects

Another mechanism leading to cross-border spill-overs is based on supply-and-demand effects. Innovation policy can increase the competitiveness of domestic producers on world markets. This can decrease world prices and lead to an oversupply of products at the expense of foreign competitors but for the benefit of foreign consumers.

For instance, if a country supports innovation policy in any given sector, countries that have a comparative advantage in this sector might see their terms of trade deteriorate as the innovation policy depresses prices in the sector (Samuelson, 2004). However, the multilateral nature of trade can provide a natural insurance mechanism against this effect, as what matters in a globalized world is comparative advantage vis-à-vis the world rather than any single country. To that effect, a study on technological progress of China in comparative advantage sectors of the United States has shown that such technological progress supported by Chinese innovation policy increases US welfare (di Giovanni, Levchenko and Zhang, 2014).

The counterpart of supply effects is demand effects. Successful innovation policies increase domestic income, which typically leads to higher import demand. This, in turn, raises world prices for the benefit of foreign producers but to the detriment of foreign consumers. Other innovation-targeted policies, like local content requirements or import tariffs, reduce demand for foreign products and, thus, hurt foreign producers.

While cross-border supply effects of industrial and innovation policy in industries such as steel or solar cells dominate the public discourse, empirical evidence as to the size and impact of such externalities is rare. This might not come as a surprise, given the difficulty in establishing clear causal evidence on the effects of innovation policies at the domestic level. In addition, tracking the cross-border effects of such policies adds another layer of complexity to the exercise and renders estimates highly imprecise.

One exception is two recent studies on supply effects in the context of subsidies to the ship-building industry and export subsidies. The study looking at ship-building finds that subsidies to the sector in the mid-2000s led to a highly inefficient global reallocation of production, from low-cost to high-cost producers, with only marginal gains for consumers (Kalouptsidi, 2018). In contrast, evidence based on the reduction of estimated subsidies with export share requirements across industries from 2000 to 2013 suggests that such subsidies led to positive welfare effects abroad while hurting domestic welfare. The effects were driven primarily by changes in consumer prices, with foreign consumers having access to cheaper products at the expense of domestic consumers that did not benefit from export subsidies (Defever and Riaño, 2015). In the context of policy responses to COVID-19, supply and demand spill-overs will probably play a large role as well (see Box C.6).

### (e) Inter-industry linkages

Finally, the cross-border externalities discussed here can be multiplied and magnified by inter-industry linkages. Some industries provide crucial inputs to other industries. Innovation policy targeted at these sectors can benefit or harm downstream industries across the world through its effect on the price and availability of inputs.

For example, import quotas should reduce the competitiveness of downstream sectors by increasing input prices, while domestic production subsidies or grants should boost the competitiveness of downstream sectors by decreasing input prices. Similarly, innovation policy targeted at downstream industries can affect upstream industries across the world by changing demand for their products.

In the age of GVCs, the importance of cross-border inter-industry linkages has increased sharply. In line with this, a growing number of studies has estimated how the effects of trade and trade policy differ with a proper accounting of such linkages (Bacchetta and Stolzenburg, 2019; Caliendo and Parro, 2015; Lee and Yi, 2018). They typically suggest that such cross-border linkages are economically meaningful as international transmitters of domestic policy. Explicit evidence for this is provided in a study on policies targeted at the steel sectors of 22 countries over the period 1975 to 2000. It finds that such policies hurt the export performance of domestic downstream industries, especially in the case of developing countries, since they lead to higher input prices and higher market concentration (Blonigen, 2016). It is reasonable to assume that such negative effects also hurt international customers of these steel industries. The COVID-19 pandemic has intensified calls for supply chain reshoring to ensure the provision of essential goods (see Box C.7).

### (f) Cross-border externalities in the digital age

Cross-border externalities are likely to intensify in the digital age for several reasons.

First, as shown in Section B, digital industries such as IT are knowledge-intensive and account for a growing share of R&D expenditures and patents. This implies that knowledge spill-overs are likely to increase as economies undergo a structural change towards a knowledge-based structure.

Second, the "winner-takes-all" characteristics of many digital industries lead to heavily concentrated markets. Such a market structure and the corresponding monopoly profits in these industries lend themselves to applications of strategic trade policy.

Third and relatedly, network externalities inherent in digital industries can cause sharper supply-and-demand effects and profit-shifting effects because

**Box C.6: Cross-border effects of policy responses to COVID-19 in the field of innovation**

Policy responses to COVID-19 are likely to have large cross-border externalities along the dimensions discussed in this section. Most importantly, research support given to the pharmaceutical industry and other entities engaged in the development of vaccines or antibody tests creates both positive knowledge spill-overs and, by eventually spurring a faster recovery of the economy, will lead to large positive global demand effects.

For example, the COVID-19 Genomics UK consortium, funded by the United Kingdom, has started to collaborate with the COVID Genomics Network, funded by Canada, in order to facilitate knowledge spill-overs (Genome Canada, 2020). Similarly, during the recent #EUvsVirus Hackathon, organized by the European Innovation Council to spur innovation related to COVID-19, three of the six challenge category winner teams consisted of members from four or more countries (European Commission, 2020).

Broad fiscal policies that benefit innovation and research among other industries also boost domestic supply and demand and, therefore, support foreign supply and demand. Evidence from the great recession of 2008 and 2009 and other contractionary periods shows that expansionary fiscal policies help to contain recessions, not just domestically, but also abroad (Auerbach and Gorodnichenko, 2013). An important aspect in this area during the present crisis is investments in digital infrastructure, which help to sustain supply and demand in the present and will facilitate trade and international cooperation in the future.

On the other hand, export restrictions on medical supplies can slow down medical innovation abroad by limiting access and raising prices for the necessary supplies and inputs to research. According to a recent report, 72 WTO members and eight non-WTO member countries have put restrictions on the exportation of medical supplies (WTO, 2020d).

Countries also compete for scarce resources such as firms at the technology frontier in vaccine development. These types of zero-sum games by design generate negative cross-border externalities. Policy responses to the Great Recession are also helpful with regards to avoiding negative spill-overs, as many of these responses contained local content requirements or conditioned eligibility on nationality which limited positive demand spill-overs, and thus the usefulness of the responses (Larch and Lechthaler, 2011). Such approaches should be avoided when responding to the current crisis.

International inter-industry linkages will multiply the effects of any policy response to COVID-19. Recent studies highlight how the effects of shutdown policies propagate through GVCs to trade partners (Gerschel, Martinez and Mejean, 2020; Sforza and Steininger, 2020). While these linkages led to a faster diffusion of the initial supply-and-demand contraction, they will also generate faster and larger positive demand and supply spill-overs from the policy responses that counter the contraction.

they allow for only very few firms in the market to maximize the network-related benefits to customers. This can lead to the sudden disappearance of formerly dominant firms, as was for instance observed in the case of Altavista, or local competitors of Facebook.

Finally, as the uptake of digital technologies across industries increases, supplying industries like IT or electronic equipment become more and more pivotal by producing general purpose technologies. If their performance improves due to innovation policies enacted in one country, this can have significant positive effects for downstream digitally enabled industries across the world and offset the potential negative supply-side effects of such policies, such as overcapacity or price depression.

### (g) Aggregate assessment of cross-border externalities

It is difficult, and highly context-specific, to asses whether cross-border externalities from innovation policies imply net benefits or net losses for foreign countries. Different externalities pull in different directions, and different country characteristics, such as market share in targeted products or the position in GVCs, have a large impact. Hence, aggregate assessments are complex and there is little established literature on the subject.

A calibration study in the context of Eastern and Western Europe suggests, for instance, that positive knowledge spill-over effects of R&D subsidies

**Box C.7: Is reshoring the best option to ensure the supply of essential goods?**

The COVID-19 pandemic has spotlighted the need to ensure a supply of essential goods such as medical supplies and personal protective equipment (PPE). Discussions have intensified among business and policymakers about reorganizing global supply chains to ensure self-sufficiency with regard to essential goods.

The calls to reorganize supply chains had started even before the COVID-19 pandemic, and a number of factors were behind this growing trend. First, rising wages in emerging countries mean that wage differentials between developed and emerging economies are shrinking, leading firms to respond by shifting production to more cost-effective locations. Second, technological progress and automation are enabling firms to locate certain types of production closer to consumer markets. Thirdly, changes in the policy environment that are raising trade costs and causing uncertainty about future policy are triggering a reorganization of supply chains. The calls for self-sufficiency in the wake of the COVID-19 pandemic could accelerate the trend of reshoring and nearshoring of supply chains.

To ensure the supply of essential goods in a pandemic, a range of policy options may be considered. One option is to establish domestic production of essential goods, in other words, to reshore the supply chain. While reshoring can guarantee supply during times of crisis, it is likely to have several drawbacks. First, only the largest and most advanced countries are likely to have the manufacturing capacity, specialized machinery and access to inputs to be capable of self-sufficiency. Second, whereas trade allows production to relocate to where it is most efficient and helps to increase access to more goods at affordable prices, reshoring policies could involve high costs in the form of government subsidies, import barriers and higher consumer prices. Furthermore, self-sufficiency is not, in itself, a guarantee of greater security. Eliminating reliance on foreign production and inputs means increased reliance on domestic production, which can also be subject to adverse shocks (Bonadio *et al.*, 2020).

Alternative policies could include increased stockpiles, diversification of sources of supply in order to avoid dependency on only a small number of countries, and flexible production capacities, enabling economies to switch production quickly to essential goods when needs arise. Economists argue that these alternative options are more cost-effective (Freund, 2020; Miroudot, 2020). In the case of medical products, international trade and cross-border supply chains not only lead to higher efficiency and lower costs, but also enable large-scale R&D to develop new medicines and medical technology (Stellinger, Berglund and Isakson, 2020).

International cooperation can play an important role in helping governments secure the supply of essential goods during crises. Governments can cooperate to collect and share information on potential concentration and bottlenecks upstream and/or to develop stress tests for essential supply chains (Fiorini, Hoekman and Yildirim, 2020; OECD, 2020). Identifying bottlenecks in supply chains and measures to address them requires cooperation between industry and government, as well as among governments. Governments could also cooperate to facilitate trade to guarantee supply chain continuity in PPE and other essential products. International cooperation is also very important with regard to the stockpiling of essential goods. The European Commission recommends that stockpiling be coordinated at the EU level and that any stockpiling by member states should be undertaken at the national level and in moderate quantities based on epidemiological indications (European Commission, 2020g).

In addition, advancements in information and communication technologies (ICTs) could significantly facilitate information management and coordination along supply chains, thus reducing the cost of business continuity. New technologies such as artificial intelligence (AI) and the Internet of Things (IoT) could be used to optimize cargo and shipment logistics and to improve autonomous driving and real-time itinerary mapping, thus increasing supply chain visibility. Blockchains and AI could further decrease transaction and compliance costs and increase the transparency of supply chains (Francisco and Swanson, 2018). Additive manufacturing, or 3D printing, could allow companies to swiftly convert manufacturing capacity to new products (WTO, 2018) – for example, during the COVID-19 pandemic, 3D printing was used to manufacture face shields and ventilators (Statt, 2020). These technologies are likely to enable firms to improve visibility across supply chain and increase supply chain resilience without the traditional costs associated with risk management (Deloitte, 2020).

are larger than negative profit-shifting effects, in particular when there are strong FDI linkages between the countries involved (Borota, Defever and Impullitti, 2019). Similar conclusions can be drawn from simulation studies, which show that cooperative subsidies tend to be higher in certain settings than non-cooperative subsidies, as this suggests that the positive externalities of R&D subsidies outweigh negative externalities (see, for example, Haaland and Kind, 2008).

Thus, it bears repeating that many cross-border externalities improve innovation, welfare and productivity abroad. A complete assessment of innovation policies and their consequences for international cooperation needs to take these positive effects into account in order to reach a balanced and efficient outcome.

For an assessment of the net effects, it is also necessary to observe that governments enact policies that are aimed at promoting or limiting both positive and negative cross-border externalities. For instance, local content requirements prevent positive demand effects to benefit foreign upstream industries. IP protection chapters in international trade agreements can limit knowledge spill-overs, as can nationality-based merger and acquisition screenings or nationality-based eligibility criteria for subsidies or government procurement.

What is also important in understanding cross-border externalities is that the different mechanisms through which cross-border externalities arise are usually not policy-specific. That is, the same type of externality can be created through a variety of policy interventions even if to a varying degree and nature. Policies as different as import tariffs and antitrust laws can both cause all the mentioned externalities – from knowledge spill-overs to supply and demand effects – and it depends on the details of these measures which effects dominate.

For instance, R&D subsidies in one country tend to create knowledge that spills over to other countries and facilitates technological leapfrogging and original innovation there (Moretti, Steinwender and Van Reenen, 2019). But R&D subsidies also can be used for profit-shifting since they facilitate entry into R&D-intensive industries (Spencer and Brander, 1983). In addition, they have supply-and-demand effects as they both raise supply in the subsidized activity and demand in supplying industries. These effects are then magnified by cross-border input output linkages, as GVCs have been shown to be particularly effective in promoting knowledge diffusion (Piermartini and Rubínová, forthcoming).

Similarly, import tariffs, by protecting domestic industries, can boost domestic innovation that eventually spills over to other countries as discussed in Section C.3. But they can also be used for profit-shifting since they reduce the output produced by foreign firms and increase entry of domestic firms. They also lead to cross-border externalities by reducing domestic demand of domestic downstream industries that now face higher input prices, and they have supply effects by boosting domestic production for world markets.

Less obvious policies, like education policies, can also create cross-border externalities, even if this occurs in the long-term. Shifting government funds to technical universities can, for instance, increase over time the output of domestic industries dependent on workers with a technical background, leading to important supply effects; and, obviously, education policy can increase knowledge spill-overs. Competition policy can be used to promote national champions and shift monopoly profits across borders, but it can also be used to stimulate international innovation by preventing competition-stifling takeovers. Tax policy, especially in the digital age with heavily concentrated markets, can also be used to shift profits across borders, but such tax policy can also be used to incentivize innovation and promote knowledge spill-overs.

These examples show that, while very different policies can create the same type of externality, it is nevertheless likely that some policies have a stronger impact on certain externalities than others. Similarly, some policies, such as export subsidies, are obviously more trade-distortive than others. In particular, non-specific measures such as education policy or basic research grants are likely to be less harmful than more direct and targeted measures, at least in the short- to medium-term.

Negative spill-overs from direct and targeted measures are likely to be smaller if they are transparent, time-limited and non-discriminatory, but the literature quantifying such differences is meagre. This emphasizes that the spill-over effects of industrial and innovation policy should be targeted for future research in order to guide policymakers who will need to attempt to regulate innovation policies and negotiate international cooperation in this area. This is of particular importance since externalities like profit-shifting and resource competition sometimes involve a "prisoner's dilemma", in which a cooperative outcome leads to higher welfare than unilateral policy-setting (Rodrik, 2020). This will be discussed more extensively in Section D.

## 5. Conclusions

This section has considered the rationales and the impact of innovation policy. The rationales for government intervention to support innovation include the public good nature of knowledge, the economy-wide spill-overs of general-purpose technologies, the market failures in financing innovation, the coordination failures in complex industries, and network externalities.

Some of these rationales are particularly important in the case of digital innovations, for a number of reasons: Big Data present public good characteristics; digital technologies are general-purpose technologies generating large benefits across the whole economy; digital products are complex and suffer from coordination failures; there are large network effects that may require various types of government action, from addressing anti-competitive behaviour to setting standards; and the adoption of digital technologies may deliver public policy objectives.

The toolkit of policies to promote innovation is vast. Innovation and innovation-related policies affect firms' decisions to engage in R&D and innovate by impacting market size, the productivity of R&D, the appropriability of research results, and product market structure.

This section has discussed the effectiveness of policies that can enhance innovation and that fall under these four categories. Although the empirical evidence currently available does not allow to fully answer the question of which policies matter most, let alone the question of which policies are most cost-effective to advance digital innovation, the findings of various extant literature streams provide useful guidance. An important take-home message from the wider literature on industrial and innovation policy is that government interventions should be grounded in sound expectations, and should be aligned with countries' static or dynamic comparative advantages. Understanding the determinants of comparative advantage in the digital age is therefore a necessary precondition for the success of innovation policy.

Like several other government policies, innovation policy can have an impact on other countries. The impact on third countries can be positive, for instance if knowledge created in one country benefits other countries as it diffuses across space over time. But it can also be negative, for instance if innovation policy in imperfectly competitive markets shifts profits across jurisdictions.

Cross-border externalities are likely to intensify in the digital age because knowledge spill-overs matter more in knowledge-based economies, because of the "winner-takes-all" characteristics of many digital industries, which lead to heavily concentrated markets, and because of the general purpose technology nature of IT and electronic equipment industries, which enable the digital sectors.

Due to both the positive and negative third-country effects of innovation policies, there might be scope for international cooperation to improve upon unilateral policy-setting. This will be discussed more extensively in Section D.

# Endnotes

1 Network externalities may give rise, in the first place, to business-stealing overinvestment in R&D. This is socially wasteful because innovator firms may acquire market shares at the expense of rivals (or capture nearly the entire market) without necessarily generating any social benefit, for instance if the innovative technology/product is only marginally better than the existing technology/product (Bloom, Van Reenen and Williams, 2019). See also Nobel Committee (2018) and Atkeson, Burstein and Chatzikonstantinou (2019) for further discussion.

2 See Succar (1987), Greenwald and Stiglitz (2006), Stokey (1991) and Young (1991) for theoretical arguments. See Wade (1990) and Pack (2000) for evidence on Chinese Taipei. Blonigen (2016) studies government policies related to steel in 22 countries. Lane (2019) studies the effects of the heavy chemical and industry drive in the Republic of Korea between 1973 and 1979.

3 See Audretsch, Keilbach and Lehmann (2006), Akcigit *et al.* (2018) and Haltiwanger, Jarmin and Miranda (2013).

4 See Brander and Krugman (1983), Helpman and Krugman (1989), Harrison and Rodríguez-Clare (2010) and Katz and Summers (1989).

5 Acemoglu, Aghion and Zilibotti (2006) emphasize the importance of the timing of the switch from an investment-based to an innovation-based growth strategy. Government intervention in the form of policies limiting product market competition or providing subsidies for investment may be useful to improve the short-run allocation of resources and to avoid the switch to an innovation-based strategy occurring too soon, but may have adverse long-run consequences, delaying or impeding altogether the switch. In the latter case, the economy is stuck in a middle-income trap, and fails to ever achieve the world technology frontier. For further discussion on the importance of switching to an innovation-based strategy along the development trajectory, see Cherif and Hasanov (2019). They emphasize the role of homegrown innovation in avoiding middle-income traps.

6 In a model by Aw, Roberts and Xu (2011), exporting and investment in R&D are two interconnected activities. More export opportunities increase the expected returns to R&D and more R&D investment that boosts productivity increases the expected returns to exporting. Both also involve an investment to overcome initial entry barriers, even though the cost of exporting is lower than the cost of conducting R&D.

7 Another study based on data for thousands of products exported by 56 economies to the United States lends some support for the non-linear relationship between innovation and competition proposed by Aghion *et al.* (2005). It finds that a decrease in tariff protection is associated with quality upgrading for products close to the world quality frontier (the best available quality), whereas the opposite holds for products far from the frontier (Amiti and Khandelwal, 2013). This relationship holds only in countries that have business environments that are sufficiently good that the competition channel is relevant.

8 Harrison and Rodríguez-Clare (2009) provide an overview of the infant industry argument's theoretical underpinnings.

9 External economies of scale refer to the benefits of industry co-location. Firms in the same industry may benefit from being located geographically close to each other because it allows them to draw upon larger pools of workers with specific skills, specialized suppliers and customers, and because proximity favours knowledge diffusion.

10 The Marshal Plan was a US programme which provided aid to Western Europe following the devastation of the Second World War.

11 There is, for instance, evidence that access restrictions to the Chinese-language version of Wikipedia in mainland China reduced contributions from contributors in economies that were not blocked, such as Chinese Taipei, Hong Kong (China), Singapore and other regions of the world, since the reach of such contributions was reduced (Zhang and Zhu, 2011).

12 Czarnitzki, Hanel and Rosa (2011), however, do not find significant differences between the recipient firms and the selected control group representing the recipients in the counterfactual situation of the absence of R&D tax credits. This implies that the firms may indeed conduct more R&D, but some are likely to invest in short-term projects that have a lower marginal rate of return than projects that would have been conducted even in the absence of R&D tax credits. As a consequence, the authors find no effect of R&D tax credits on more general firm performance indicators such as profits or domestic market share.

13 In research using US data and considering corporate and personal income taxation rather than innovation-focused policies such as R&D tax credits, Akcigit *et al.* (2018) show that taxes matter for innovation: higher personal and corporate income taxes negatively affect the quantity and quality of inventive activity.

14 Manelici and Pantea (2019) study the impact of a personal income tax break to programmers working on software development in IT sectors, implemented by Romania in 2001. They show that, as a result of this policy change, the IT sector grew faster in Romania than in otherwise similar countries. Downstream sectors relying more on IT services also grew faster in Romania after 2001. These results suggest that this policy has been effective in promoting the development of the IT sector, a sector typically seen as key to the transition to a knowledge economy.

15 Moretti and Wilson (2017) show that within-US migration by star scientists is very responsive to changes in personal and business tax differentials across US states. Akcigit, Baslandze and Stantcheva (2016) study the effect of top tax rates on "superstar" inventors' international mobility since 1977. They find that superstar inventors' location choices are significantly affected by top tax rates. See also sections C.3(g) and C.4 for further discussion of the general equilibrium effects of innovation policies.

16 We have pioneered this approach at the UCL Institute for Innovation and Public Purpose (IIPP), where we hosted a commission on mission-oriented industrial strategy concentrating on the United Kingdom but applicable in a global context.

17 IIPP has explored this topic in depth in a study of innovation in the pharmaceutical industry (UCL Institute for Innovation and Public Purpose (IIPP), 2018).

18 Using propensity score matching to tackle selection issues (i.e. R&D grants are not randomly assigned, but depend in part on unobservable firm characteristics), Le and Jaffe (2017) examine the impact of R&D grant receipt on innovation outcomes for firms in New Zealand. They show that that the innovation performances of grant-receiving firms exceed that of "similar" (propensity-matched) firms that do not receive grants. In particular, they find a positive effect on the probability that a firm applied for a patent during 2005–09. They also find that R&D grants have a stronger effect on more novel innovation than on incremental innovation: receiving an R&D grant almost doubles the probability that a firm introduces new goods and services to the world, while its effects on process innovation and any product innovation are relatively much weaker. Finally, they show that R&D project grants have much larger effects on innovation outcomes than R&D capability-building grants. Le and Jaffe (2017) interpret the latter result as evidence for the public policy value of R&D project grants.

19 See Slavtchev and Wiederhold (2016, footnote 2 on page 46). They also provide for references to studies showing a positive impact of government purchases on firm-level innovation. For a very detailed overview of the literature studying the nexus between public procurement and innovation, see Lenderink, Johannes and Voordijk (2019).

20 The measure the technological intensity of public procurement employed by Slavtchev and Wiederhold (2016) is the share of federal procurement in high-tech industries performed in a state in total federal procurement in that state, considering only non-R&D procurement contracts awarded to private-sector firms.

21 In the case of Ecuador, a developing country, the above-mentioned paper by Fernández-Sastre and Montalvo-Quizhpi (2019) finds that, in contrast to innovation support programmes, public procurement does not induce firms to invest in R&D activities, even for the largest contracts.

22 The increases in private R&D expenditures as a result of raising defence expenditures, as estimated by Moretti, Steinwender and Van Reenen (2019), do not just reflect higher wages and input prices caused by increased demand. The authors show, in fact, significant positive effects on the employment of R&D personnel. The fact that higher demand for the labour of specialized R&D workers raises their employment, and not only their wages, is consistent with a fairly elastic labour supply of specialized R&D workers.

23 In an online survey among representative samples of the population in seven EU countries (Denmark, France, Germany, Italy, the Netherlands, Portugal and the United Kingdom), 73.9 per cent of the 7,664 participants stated that they would be willing to be vaccinated against COVID-19 if a vaccine were available. A further 18.9 per cent of respondents stated that they were not sure, and 7.2 per cent stated that they do not want to be vaccinated (Neumann-Bohme *et al.*, 2020). In a survey conducted in the United States between April 29 and May 5 (Pew Research Center, 2020), 72 per cent of adults said they would definitely (42 per cent) or probably (30 per cent) be vaccinated against COVID-19 if a vaccine were available, while about a quarter (27 per cent) said they would not.

24 See Whitley (2003) for a discussion of the merits of decentralized competition in developing highly novel and disruptive technologies.

25 See Kremer, Levin and Snyder (2020) on the economics of advance market commitments for vaccine development.

26 A positive correlation is obtained both in a sub-sample of developing economies and in a sub-sample of developing economies. The interaction between a "developed" dummy variable and IPR protection is not significantly correlated with the share of ICT patents in total patents in the full sample of 91 economies.

27 Qualitatively similar conclusions are reached by Watal and Dai (2019). Using launch data from 1980 to 2017 covering 70 markets, they find that the introduction of product patent for pharmaceuticals in the patent law has a positive effect on launch likelihood, especially for innovative pharmaceuticals. This effect is, however, quite limited in low-income markets.

28 Focusing on the biomedical industry, Hegde and Luo (2018) show that the impact of a policy change in US regulations (according to which patent applications have to be published 18 months after filing) made US patent applications less likely to be licensed after the patent was granted, and more likely to be licensed between publication and grant. This suggests that disclosure facilitates sales and transactions in the market for ideas.

29 Survey evidence reported by Williams (2017) suggests that, from the perspective of firms, patents are not essential for spurring R&D investments, except in chemicals, and in particular pharmaceuticals. Empirical studies based on patent law changes (Lerner, 2009; Sakakibara and Branstetter, 2001) also find little evidence that stronger patent rights encourage research investments. Finally, Budish, Roin and Williams (2015), who exploit variation in clinical trial lengths in the context of cancer research, find evidence of a positive impact of shortening clinical trial lengths on R&D investment, but they cannot isolate the importance of patents as opposed to other factors.

30 Survey evidence suggests that neither university nor industrial researchers tend to abandon worthwhile projects because of issues of access to intellectual property. Econometric evidence by Williams (2013) and Murray *et al.* (2016) suggests that non-patent forms of IP protection can reduce follow-up innovation in the field of biomedical sciences. Conversely, Galasso and Schankerman (2015) find that removing patent rights by court invalidation increases subsequent research related to the focal patent, as measured by later citations, in sectors such

as computers, electronics and medical instruments, but not in others, such as drugs, chemicals, or mechanical technologies. Finally, Azoulay *et al.* (2019b), who consider patents on human genes, find no evidence that they have any impact on follow-on innovation.

31 The WTO TRIPS Agreement allows compulsory licensing (defined in Article 31 as "other use without authorization of the right-holder"), provided that the person or company applying for a licence has first attempted unsuccessfully to obtain a voluntary licence from the right-holder on reasonable commercial terms, and that if a compulsory licence is issued, adequate remuneration is paid to the patent-holder. To save time, the former requirement does not need to be met in case of national emergencies or other circumstances of extreme urgency. The original TRIPS Agreement (Article 31) restricted the use of compulsory licensing mainly to supply the domestic market. The Annex to the Amendment of the TRIPS Agreement, which came into force on 23 January 2017, allows compulsory licensing for production and subsequent exporting of pharmaceutical products, including medicines, vaccines and diagnostics, needed to fight an epidemic. This is relevant in the current COVID-19-related health crisis, as discussed in Section D. For detailed information on the use of compulsory licensing in the pharmaceutical sector, see WTO, WIPO and WHO (2020).

32 The TEWA permitted US firms to violate enemy-owned patents if they contributed to the war effort. As the war dragged on, the TWEA became more and more punitive. In November 1918, US Congress amended the TWEA to confiscate all enemy-owned patents. By February 1919, German-owned patents were systematically licensed to US firms.

33 See also Aguiar and Waldfogel (2018). While not focusing on innovation (quality of music), Oberholzer-Gee and Strumpf (2007) present evidence that file-sharing does not reduce the legal sales of music.

34 Open-source projects more typically use permissive licences, whereby the user retains the possibility of using the code as he or she wishes, including for developing marketable proprietary software (Tirole, 2017). This is the case, for instance, of BDS (Berkeley Software Distribution) and Apache (a free web-server software that powers nearly half of all websites in the world).

35 See https://hostingtribunal.com/blog/linux-statistics/#gref.

36 Consider the extreme case of fixed supply of scientists and engineers. Higher demand for scientists and engineers would simply increase their wages, without increasing innovation. Obviously, supply may be fixed at any given point in time, but elastic (i.e. upward-sloping) in the long run. Also, in the presence of substitutability between scientists/engineers and other factors of innovation production, an increase in their relative price would induce a decrease in their relative utilization (Bloom, Van Reenen and Williams, 2019).

37 Although he does not focus on STEM graduates, Mitrunen (2019) offers interesting evidence that human capital development can be an endogenous response to high-skill industry-biased government policy, such as the one implemented by Finland in the aftermath of the Second World War to be able to pay war reparations to the Soviet Union.

38 See footnote 10 in Kerr *et al.* (2016) for a list of these studies. Hunt and Gauthier-Loiselle (2010) is among the seminal papers in this literature. They document that a 1 percentage point increase in immigrant college graduates' population share increases patents per capita by 9 to 18 per cent. They also argue for a spill-over effect into the rest of the population. Several other studies document how exogenous shocks to immigration affected innovation. Moser, Voena and Waldinger (2014), for instance, show that American innovation in chemistry was boosted by the arrival of Jewish scientists who were expelled by the Nazi regime in Germany in the 1930s. Doran and Yoon (2020) and Moser and San (2020) show that quotas introduced in the 1920s in the United States that more strongly affected migrants from Southern and Eastern European countries than migrants from Northern European countries discouraged Eastern and Southern European countries from migrating to the United States and reduced aggregate invention.

39 See footnote 11 in Kerr *et al.* (2016) for a list of these studies. The most relevant study is Borjas and Doran (2012). They consider the post-1992 influx of Soviet mathematicians, finding a negative productivity impact on their US counterparts, in particular on those mathematicians whose research overlapped with that of the Soviets.

40 See footnote 12 in Kerr *et al.* (2016) for a list of these studies. In a recent contribution, Fassio, Montobbio and Venturini (2019) study the effects of skilled migration on innovation (proxied by patent citations) in France, Germany and the United Kingdom. They show that highly educated migrants have a positive effect on innovation, although this effect is about one-third the effect of highly educated natives: a 1 per cent increase in the number of educated natives (immigrants) leads to a 0.3 (0.1) per cent increase in the citation-weighted number of patents. The effects are stronger in industries with low levels of over-education, high levels of foreign direct investment (FDI) and openness to trade, and in industries with higher ethnic diversity.

41 Offers of permanent residency prove more attractive to non-high-skilled workers than to high-skilled workers, thereby reducing the human capital content of labour flows according to Czaika and Parsons (2017). Family reunification, not captured in their dataset, also tends to be biased towards low-skilled groups, at least in the United States (Kerr *et al.*, 2016).

42 See for instance Correa (2012) who, using the same dataset as Aghion *et al.* (2005), finds a structural break in the early 1980s. This coincides with establishment of the US Court of Appeals for the Federal Circuit (CAFC) in 1982. Correa (2012) shows that, in the United States, there is a positive innovation-competition relationship in the pre-CAFC period (1973-82) and no relationship at all in the post-CAFC period (1983-94). See World Bank (2017, p. 49), for more details and explanation of these results.

43 For instance, Bassanini and Ernst (2002) find a negative correlation between product market regulations and the intensity of R&D expenditure in OECD countries. Similar results are obtained by other studies cited by Blind (2016, p. 454). In the case of a developing country (India), using a sample of 291 manufacturing firms, Kumar and Saqib (1996) show that in cases where the entry of new firms in

a market is restricted by government policy, the absence of competitive pressure reduces the likelihood of firms undertaking R&D. However, the competitive pressure does not influence the intensity of R&D expenditures of firms once they have decided to invest in R&D. Franco, Pieri and Venturini (2016) show that upstream restrictive service regulation reduces R&D efficiency of downstream manufacturing in OECD countries. Using firm-level data for 100 developing countries, Hoekman and Shepherd (2017) show that services trade restrictiveness indices negatively impact manufactured exports performance. Similar evidence for sub-Saharan African countries is presented by Arnold, Mattoo and Narciso (2008).

44 The use of compulsory licensing (defined as "other use without authorization of the right-holder") to remedy anti-competitive practices is foreseen and disciplined in Article 31 of the WTO TRIPS Agreement.

45 A larger-scale presence of complementary specialized inputs and professional service providers is also relevant (Kerr *et al.* 2017).

46 See Kerr and Robert-Nicoud (2019), pages 15-16, for a discussion of the importance of the location of anchor firms and for a review of some recent studies providing historical accounts of the shakeout process of emerging frontier technologies.

47 Accelerators use competitive entry and intensive support. They usually provide an on-site workplace, as well as business skills training, intensive mentoring and networking activity. Incubators also provide workplace and training relevant to business, but entry is less competitive, and the level of support is limited to minimal mentorship. Science parks are agglomeration of high-tech firms at walking distance from each other.

48 Between-country inequality related to innovation policy is discussed in Section D.

49 Akcigit, Grigsby and Nicholas (2017) also find a positive correlation between patenting intensity and social mobility across the United States over the past 150 years.