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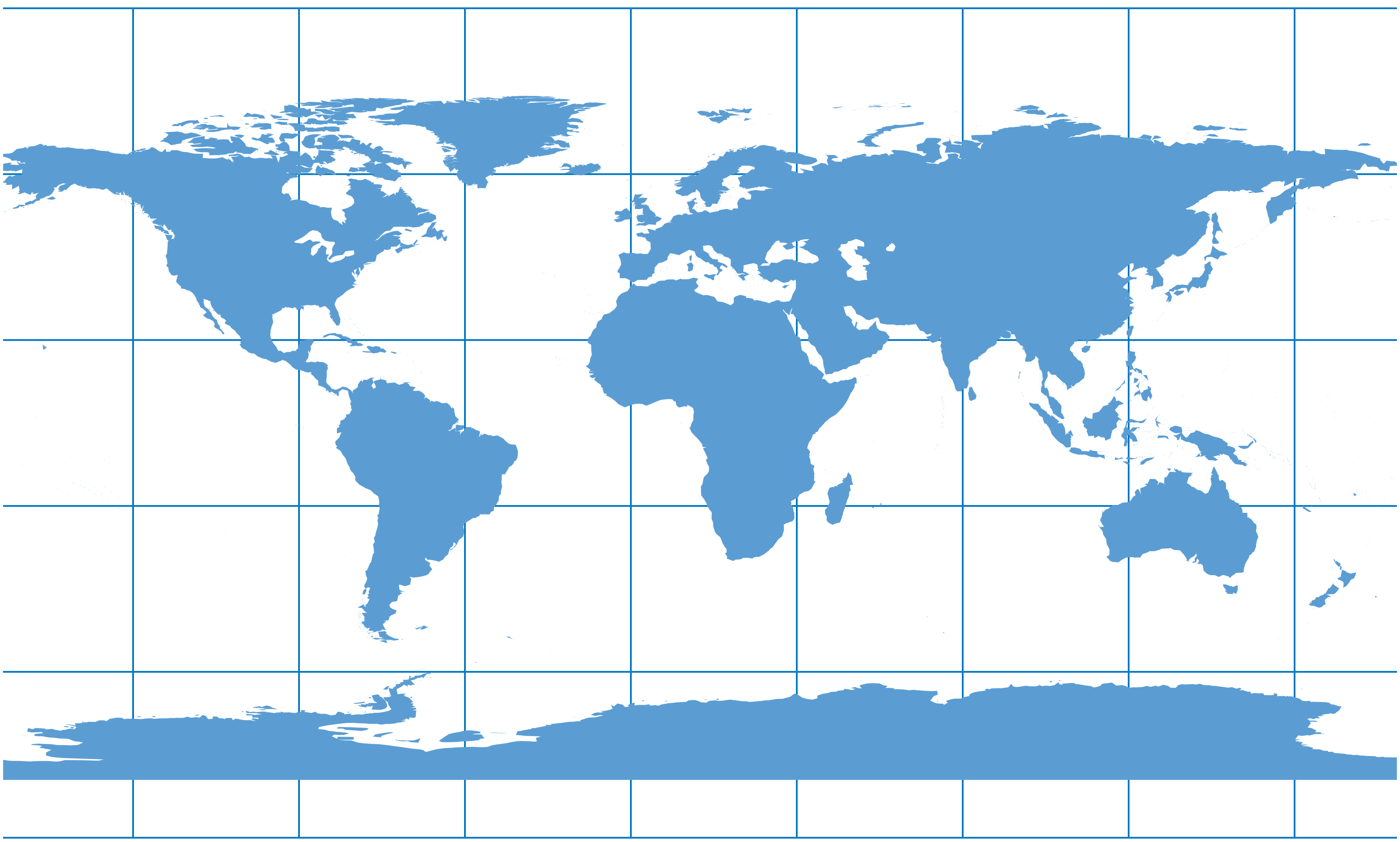
Frontier technologies for sustainable development



United Nations
New York, 2018

Chapter IV

Fostering innovation, diffusion and adoption

Introduction

The previous chapters discussed the importance of new technologies, their introduction in advanced countries, and the slow technological progress in many developing countries that underpins the development divide. The present chapter focuses on how countries can foster innovation and how other countries adapt and adopt these innovations and promote economic growth.

Technological innovations that create more efficient firms and workers are part of a virtuous cycle

Technological advances during the past three centuries enabled some societies to leap forward, supporting ever larger populations, reducing poverty, increasing longevity and pushing the frontier of knowledge and technology ever forward. Innovation created more efficient firms and workers, which in turn created more innovative economies. This virtuous cycle created more dynamic, competitive and sophisticated economies.

Innovation in frontier technologies is becoming more concentrated, and the firms and countries that fall behind can find themselves facing a widening technology and development gap

However, many countries and communities within them have not had the same experience. As chapters II and III of this *Survey* show, there are large and growing differences between and within countries in terms of the ability to innovate, access and use technologies. Many developing countries are yet to fully utilize the technological breakthroughs of the past and, increasingly, innovation in frontier technologies is concentrated in a few firms and in a few countries. Many developing countries, particularly least developed countries (LDCs) that are falling behind in adopting and using new technologies, can find themselves in a technology and income trap, continuing to produce basic goods and services that do not encourage innovation and enable structural transformation. It in turn results in a growing development gap.

In discussing the links between development gaps and technological divides, this chapter will first explain the connection between innovation and economic growth, and the importance of each for sustainable development. Innovation can be understood as a broad-based activity which subsumes both *process* innovation, reflecting the ability of firms and economies to find new ways of producing existing goods and services; and *product* innovation, i.e., the invention of new products and services. Innovation does not always signify a technological breakthrough — a grand-scale, one-of-a-kind invention. Innovation, broadly speaking, also entails improvements and improvisations of processes and products, which can be small-scale, incremental and even imperceptible.

This chapter explains how both process and product innovations are important for growth. Product and process innovations go hand in hand and complement each other. Unfortunately, while relatively large developing countries have been able to innovate and achieve high rates of growth— often adopting and using technologies developed in other countries — this is not the case for many others.

It is argued here that faster innovation, great or small, and closing the technological divide are important requirements for achievement of higher and sustained economic growth and for a more equitable distribution of economic gains. The chapter discusses key elements of the innovation and diffusion processes, which have implications for the technological divide between developed and developing countries and within those countries. It also highlights four factors that could lead to an even wider divide: (a) continued divergence in the ability of firms and countries to innovate and adopt existing technologies; (b) growing market power concentration; (c) increasingly more stringent and restrictive intellectual property rights (IPR) regimes; and (d) possible confinement of technology diffusion to firms of similar technological capacities.

Keeping up with and catching up to the technological frontier are not automatic processes: they depend on how well a country's innovation system is developed and managed

The chapter discusses the role of Governments in closing the technological divide. For countries and firms, keeping up with and catching up to the technological frontier will depend on how well they can develop and manage their national innovation system (NIS) — a system of interconnected institutions whose aim is to create, store and transfer new technologies. A global technological frontier is broadly defined as the vanguard of technological development worldwide, represented by the set of the most cutting-edge innovations available at the global level. On the other hand, a country's own technological frontier is defined by the set of the most advanced technologies which that country's leading firms or research institutes are capable of employing. In empirical studies, the technological frontier is typically proxied by the productivity of the most productive country or firm, given the close links between technology and productivity, which is discussed subsequently.

Governments play an important role, together with the private sector, in the development of national innovation systems

Within most national innovation systems, the private sector will continue to lead the development of cutting-edge technologies and processes. Nevertheless, Governments play a central role in facilitating the system's development, through establishing and maintaining enabling infrastructures and an institutional environment that incentivizes technology innovation and adoption. The international community has an important role to play as well, as economies and technologies are connected across borders. Various internationally agreed instruments, such as the Addis Ababa Action Agenda of the Third International Conference on Financing for Development,[1] set out the commitment of the technologically advanced countries to help other countries access and adopt new technologies.

A tale of two divides: technology and development

The introduction of new technologies is central to an economy's ability to grow. Indeed, investigation into how countries have historically achieved prosperity reveals the emergence of technology as a central actor. It is no surprise, then, that technology and the process of innovation from which it emerges feature as key factors in modern growth theory.

As firms incorporate new technologies into their operations, they also open up a pathway to continuous learning and the accumulation of new capabilities

Technology helps determine a country's productivity, allowing it to extract more value from a given level of resources, including labour, capital and natural resources. Technology creates new economic opportunities and jobs, which includes creating more capable firms and workers, enabling new business models and connecting many firms and individuals to formal marketplaces. More capable firms and workers in turn create more dynamic, competitive and innovative economies. The efforts of firms to incorporate new technologies and techniques open up a pathway to continuous learning and the accumulation of new capabilities, which triggers a process of structural transformation within an economy.

1 General Assembly resolution 69/313, annex.

Technological change and economic growth

The speed of innovation and how it diffuses determine technological progress, consequently influencing productivity and economic growth

A country's ability to achieve and sustain long-term economic growth is determined by its ability to increase productivity through the use of better technology, together with human and physical capital. New technologies release new capabilities in human and physical capital, expanding the possibilities for firms (see box IV.1 for a discussion on the theoretical underpinnings of technology's effects on growth). How quickly innovation occurs and how it spreads throughout an economy determine the path and speed of technological progress, which has implications for productivity and economic growth (Benhabib, Perla and Tonetti, 2017). In a country with lower barriers to innovation diffusion, laggard firms are easily able to adopt new innovations and become competitive. This holds true also at the country level, where countries can grow by pushing the technological frontier or catch up by making use of available foreign knowledge and technology.

History provides us with some examples of this mechanism at work. The period of the first industrial revolution, which extended roughly from the late eighteenth to the early part of the nineteenth century, represented the dawn of what we now consider "modern" economic growth — growth that is driven by technological change. Innovation of processes and technologies led to a growing mastery of the use of energy, relieving the principal limitations to production at that time (Vickers and Ziebarth, 2017).

More recently, economies that have successfully developed their productive structures—such as Japan, the Republic of Korea, Singapore and Taiwan Province of China — did so by following the pattern of industrialization of the previous century. Those economies took advantage of their latecomer status, making use of available technology, process innovations, and their lower factor costs and mass production capacities to export cost-sensitive products.[2]

These examples notwithstanding, early empirical studies did not find evidence that all economies converge to similar levels of per capita income, as predicted by neoclassical growth theory. As of the present moment, economic convergence has been limited mostly to today's developed countries (see for example, Baumol, 1986). The slower growth of initially poorer countries, as revealed in the historical data, supported arguments that the world has in fact experienced income divergence (Pritchett, 1997). More recent studies on the rapid growth of emerging and developing countries (Derviş, 2012; Fukase and Martin, 2017) have added to this understanding. One important finding is that relatively large developing countries, in which firms are taking advantage of lower wages to enter the labour-intensive production stages offshored by developed countries, have been able to reduce the income gap between them and the developed countries. They have also been able to take advantage of global supply chains (Baldwin, 2016).[3]

Accelerating but unequal technological diffusion

One possible explanation for why many countries do not converge despite the theoretical potential is that they may lack the ability to use existing technologies owing to resource

2 This point was first argued by Gerschenkron (1962). More recent discussions on the advantages enjoyed by "latecomer" countries are found in Lee and Mathews (2013) and Lee (2013; 2016).

3 Baldwin (2016) specifically mentions six countries that achieved notable convergence, recently gaining a global share of manufacturing: China, India, Indonesia, Poland, the Republic of Korea and Thailand.

Box IV.1

Technology as a foundation for growth

What drives the increasingly large gaps in income per capita across countries is one of the central puzzles of development economics. Since the mid-twentieth century, economists have developed various theories to describe the drivers of economic growth. Three main theoretical frameworks are recognized in the economics literature: the Harrod-Domar model, the neoclassical model and the theory of endogenous growth. The role of technology for growth, and how technology is accumulated, constitute a central concern under each of these frameworks and how they address this concern is a key differentiator among them.

In their work in the 1940s, Roy Harrod and Evsey Domar attributed the rate of growth directly to the savings rate, which is a behavioural variable, and the incremental capital-output ratio (ICOR), which is a metric related to technology. Within this framework, faster growth requires a higher savings rate, or a lower capital-output ratio. The simplicity of this model was very attractive for countries seeking a clear policy objective. For a given ICOR and a target rate of growth, policymakers simply needed to achieve a certain savings rate. The Harrod-Domar model suffered from instabilities, however, owing to its fixed capital-output ratio specification. Any deviations would result in rising or falling unemployment rates or capacity utilization.

The Solow-Swan growth model ushered in the neoclassical approach, under which technological changes were recognized as the driver of economic growth. In that model, the capital-output ratio is determined by the neoclassical production function. Output depends on capital, labour and technological progress. This framework defines a stable "steady state" where output per labour (adjusted for technology) is constant and depends on the savings rate, population growth and technological progress. Per capita income growth (and the marginal product of labour) depends on technological progress (the level of income per capita depends on the savings rate and population growth). The neoclassical approach led to a consensus that knowledge, which leads to technological innovation, was the driver of long-run economic growth. However, this model does not explain how technological changes occur, and therefore fails to explain the most important determinant of the growth rate.

This problem led to the development of models where technological progress is a function of endogenous factors such as capital, research and development (R&D), spillover effects, the quality of human capital and technology transfers, among others. These models may differ in their specification, but all recognize the important role of innovation in determining long-run economic growth.

A subset of these endogenous growth models, so-called evolutionary-institutional theories, postulate that technological progress is primarily a function of the organization and efficiency of management of R&D resources, starting from the firm level. These models promote the concept of the national innovation system as a means, for countries, of driving technological change. This is particularly important for developing countries that, while resource-constrained, are still attempting to keep up with, and catch up to, more advanced countries.

Hidalgo and Hausmann (2009) build on this framework with their concept of "product space". In their specification, countries grow by expanding production of existing products and by producing entirely new products. That is, countries combine their existing capacities (technology, capital, labour, etc.) in new ways. They also innovate, accumulating new knowledge and capabilities to develop yet more products. In this way, innovation and diffusion advance the multiplicity of knowledge embedded in an economic system, which allows it to produce more sophisticated products and therefore grow and develop.

limitations. This may be a result of a growing concentration of technology creation in a few countries and firms and of insufficient diffusion of technology within countries.[4]

As documented in chapters II and III of this *Survey*, there are large and growing differences between and within countries with respect to their ability to innovate, access and use technologies. Many developing countries are yet to fully utilize the technological breakthroughs of the past. Also, the development of new technologies is increasingly concentrated in a few countries and a few firms.

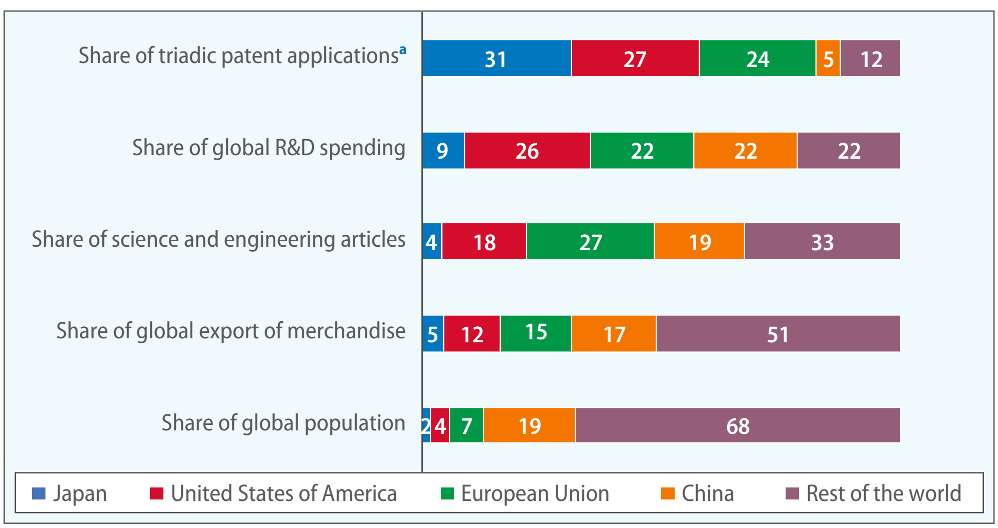
The technological divide between countries is significant — and particularly acute in the realm of frontier technologies

The technological divide between developed countries and the rest of the world economy, when measured by the numbers of patent applications or research and development (R&D) expenditures, is wide and growing. China, the European Union, Japan and the United States of America, accounting for 32 per cent of the world's population in 2015, collectively account for a far larger global share in scientific publications (67 per cent), R&D spending (78 per cent) and triadic patent applications (88 per cent) (figure IV.1). The technological divide is even more acute in the realm of frontier technologies. Fujii and Managi (2017) report that the United States alone accounted for an overwhelming 75 per cent of global artificial intelligence (AI) patents granted during 2016–2017.

At the same time, the cross-border diffusion of technology has accelerated. Using data on 25 different inventions in the last 200 years, researchers found that new technologies have diffused across countries at a faster pace (Comin and Hobijn, 2010; Comin and Mestieri Ferrer, 2013). More recent technologies, such as cell phones and the Internet, have arrived in developing countries just a few years after they were first invented in developed

Figure IV.1

Share of global for various activities, selected countries and the European Union, 2015



Sources: National Science Board (2016); OECD.Stat; UN/DESA, Population Division (2017); UIS.Stat; and World Trade Organization (2017).

a Triadic patents are a set of patents filed at the three major patent offices (European Patent Office, Japan Patent Office and United States Patent and Trademark Office) to protect the same invention.

4 A closely related challenge is the "digital divide", which is defined as the gap in use of digital technology across communities. For more specific discussions on the characteristics, trends and determinants of the digital divide, see *United Nations E-Government Survey 2014* (United Nations, 2014).

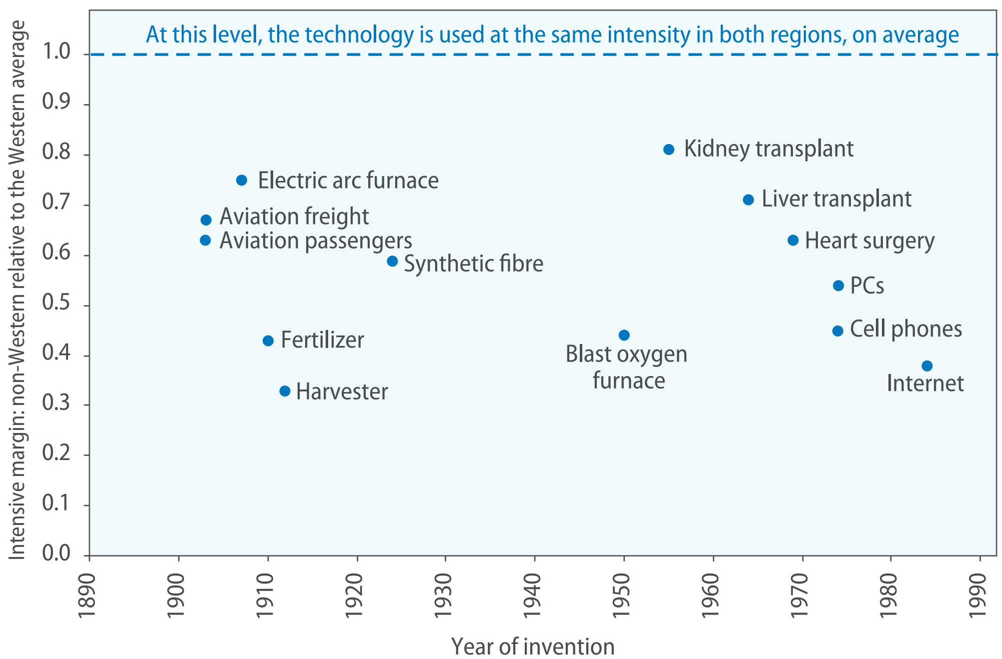
countries. This can likely be attributed to the rapid pace of globalization and the digital revolution, which have taken place in recent decades.

Acceleration of cross-border technology adoption masks the slower pace of technology diffusion within countries

However, the acceleration of technology adoption across countries masks the slower pace of diffusion of these technologies within countries. Developing countries struggle to employ technologies with the same degree of intensity and versatility as developed countries. Even as new technologies have quickly become available to all countries, it takes longer for them to be as pervasive and widely used as in developed countries.

Figure IV.2 displays the differences in the average intensity of use of selected technologies in "non-Western" as compared with "Western" countries.[5] This "intensive margin" measures the differences between the two country groups in terms of the number of users of the technology (e.g., the number of cell phones or computers per capita) and the efficiency with which the technology is used (e.g., tons of Bessemer steel produced with the technology).[6]

Figure IV.2
Intensity of use of selected technologies by "non-Western" relative to "Western" countries, 1890–1990



Source: Comin and Mestieri Ferrer (2013).

Note: A value of 1 represents equal intensity between the country groups.

5 The division of countries into two groups, namely, "Western" and "non-Western", was the approach used by Comin and Mestieri Ferrer (2013) in a seminal study. They followed the definition of Maddison (2004). The study categorizes the following countries as Western: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, New Zealand, Norway, Sweden, Switzerland, the United Kingdom of Great Britain and Northern Ireland and the United States of America.

6 The "extensive margin", by contrast, captures the fraction of potential adopters that use the technology (for example, the fraction of farmers that have adopted a new type of hybrid seed).

The difference between the two groups in how intensively each technology is used is significant. For example, the intensity of Internet use in the median non-Western country is approximately one third that in the median Western country.[7] For all technologies, the average level of adoption by the average non-Western country is slightly more than half the average adoption level for Western countries (54 per cent).

Closing the technology divides

If countries are to achieve higher, sustained economic growth and for there to be a more equitable distribution of economic gains, they must fulfil the important requirement of closing the technological divide. All the more so, as new frontier technologies are rapidly changing the make-up of industries and sectors, threatening existing comparative advantages based on traditional factors of production.

Rapid technological change presents opportunities for developing or otherwise latecomer countries…

Fortunately, periods of rapid technological change are times of opportunity for developing or otherwise latecomer countries. Firms that are not saddled with large investments in legacy equipment and obsolete methods of production can explore ways to develop new products with emerging technologies (Lee and Mathews, 2013; Lee, 2016). Countries may not necessarily need a twentieth century industrial base to build a twenty-first century bio-, nano- or information economy. Indeed, a twentieth century industrial base may be a hindrance. It may be easier for a firm without large capital investments to run a new 3D printer to manufacture a specific part rather than master all of the steps required to make that part the traditional way (Hausmann, 2017). Nevertheless, as will be discussed in a later section, the speed of adoption of newly emerging technologies will depend on a wide range of factors. Therefore, it remains difficult to predict the diffusion trajectory of frontier technologies.

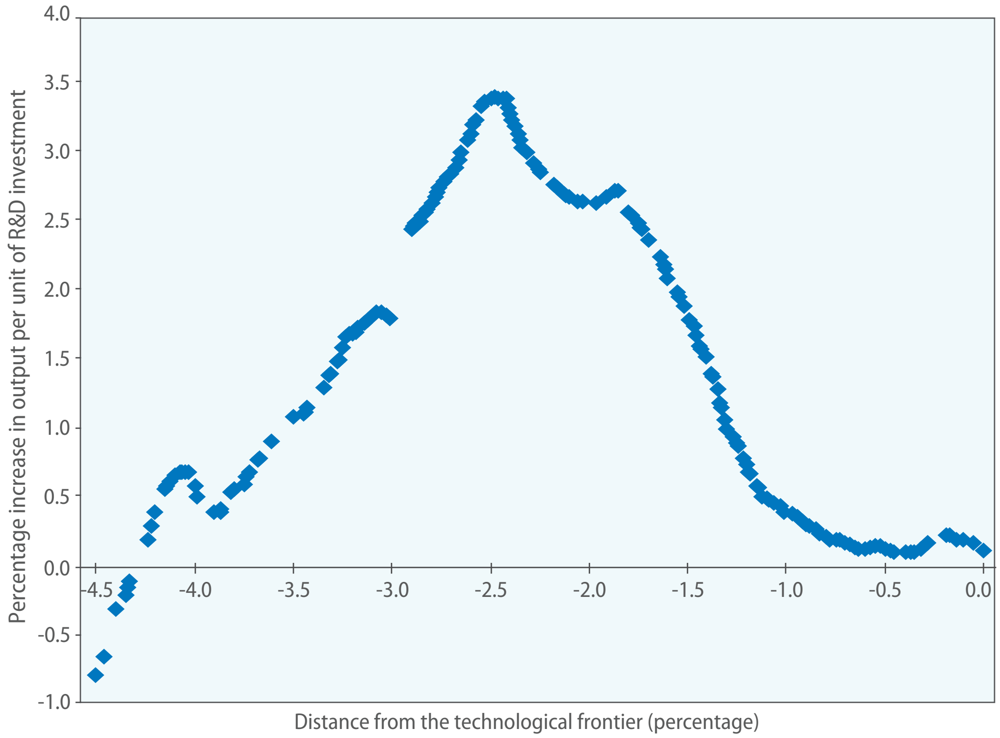
…but firms in those countries generally face difficult choices concerning technology investment

In particular, firms in developing countries generally face very difficult choices with respect to investing in technology. Figure IV.3, which portrays this challenge, measures the rate of return to R&D spending according to the distance of countries from the global technological frontier (denoted as zero at the far right along the horizontal axis). For countries that are close to or at the frontier and for countries that are farthest from the frontier (situated at the far left), the returns to R&D spending are small or negative. The largest returns to R&D spending occur in countries that are at a middle distance from the technological frontier. These countries have the capacities and complementary infrastructure required to adopt existing technologies and take advantage of the productivity gains that they yield (Cirera and Maloney, 2017; Goñi and Maloney, 2017).

Countries with intermediate levels of productive capacity and knowledge enjoy an advantage. They can use their existing capacities together with existing and new technologies to expand into many new activities. Countries with high and low levels of productive capacities face more difficulties. Advanced countries are already highly diversified, make most of the existing products and have limited options for copying more advanced products. These countries can progress further only by innovating processes and products that expand their technological frontier. At the other end of the spectrum, countries with few capabilities find it difficult to adopt existing technologies and methods, owing to limitations related to complementary factors, including knowledge, capital, technology and infrastructure.

7 A value of 1 signifies that the technology is used with equal intensity in both groups of countries. A value below 1 signifies that the technology is used relatively less intensively in non-Western countries.

Figure IV.3
Rate of return to R&D according to distance from the technological frontier



Source: Cirera and Maloney (2017), figure 3.2.

Note: The technological frontier is denoted as zero on the horizontal axis and is measured as the highest GDP per capita (in constant prices) in a given period of time. Each point on the horizontal axis, therefore, measures the distance of a certain country at a certain time from the contemporary technological frontier. The horizontal distance is calculated as the percentage difference between a country's constant GDP per capita and that of the highest constant GDP per capita in the same period.

Without a clear business case to be made for investing in advanced technologies (in terms of capital and human costs as well as expected revenues), firms will find it risky to make the jump into new markets and production techniques. This is made even more difficult by strong IPR rules which help entrench the dominance of a few firms. Another barrier in frontier technologies may be the large concentration of market power in a few large firms, driven by economies of scale, network effects and inadequate antitrust enforcement.

Making existing technologies more accessible and building an innovative economy are difficult policy challenges and there are not many countries that have managed to enable this type of technological upgrading. In recent decades, computer-aided design and manufacturing have allowed some countries to participate in global value chains of increasingly complicated products. This trend might continue, rewarding those that invest in new technologies. In his study of how the Republic of Korea managed to transform its economy, Lee (2013; 2016) demonstrates the power of the successful implementation of such a strategy at the national level, suggesting that the fate of countries at an early stage of development is not determined simply by their comparative advantage and their industrial progress is not dictated by spontaneous market outcomes. Technological upgrading is possible, and Governments can influence this process.

Market-based solutions for technology diffusion need to be supported by a well-functioning national innovation system

Because of the importance of private actors in innovation (see section on the evolving national innovation system below), market-based solutions for technology diffusion need to be supported by a well-functioning NIS, capable, inter alia, of identifying key challenges, directing research agendas, providing funding sources, setting priorities and establishing appropriate IPR regimes. Governments should work with other actors within the innovation systems to address any missing complementarities, such as physical and human capital, whose lack limits innovation and its positive externalities. As shown above, these missing complementarities become more important the farther a country or firm lies from the technological frontier. Regardless of how much a country invests in innovation and technology, if it lacks enough machine, trained workers, appropriate managerial and organization know-how, or complementary infrastructure and institutional arrangements, the returns to that investment will be low (Cirera and Maloney, 2017).

This highlights the importance of understanding the distinctions between leading and lagging national innovation systems. As will be discussed directly below, these two types of systems differ typically in terms of some of their broad features, such as the balance among the roles of different actors, the extent of their reliance on foreign technologies, and their institutional arrangements and complementary infrastructures. They therefore also differ as regards the sets of challenges that they face in their efforts to support technological development.

The evolving national innovation system

At the core of every country's technological endeavours lies its national innovation system (NIS). An NIS is defined as the "set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process" (Metcalfe, 1995). As such, "it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies".

At work within an NIS are several key processes: innovation, diffusion, adoption and adaptation. Innovation, which has a broad scope, subsumes both process and product innovations, as already noted. The generation of an initial form of innovation is followed by its diffusion, through which the innovation is broadly disseminated over time among the members of the system. The diffusion process reflects user acceptance of the innovation; and the rate of its adoption by individuals determines the speed of its diffusion at the macro level. Closely related to adoption is adaptation, which refers to the tweaking of the original technology to render it a better fit for local conditions.

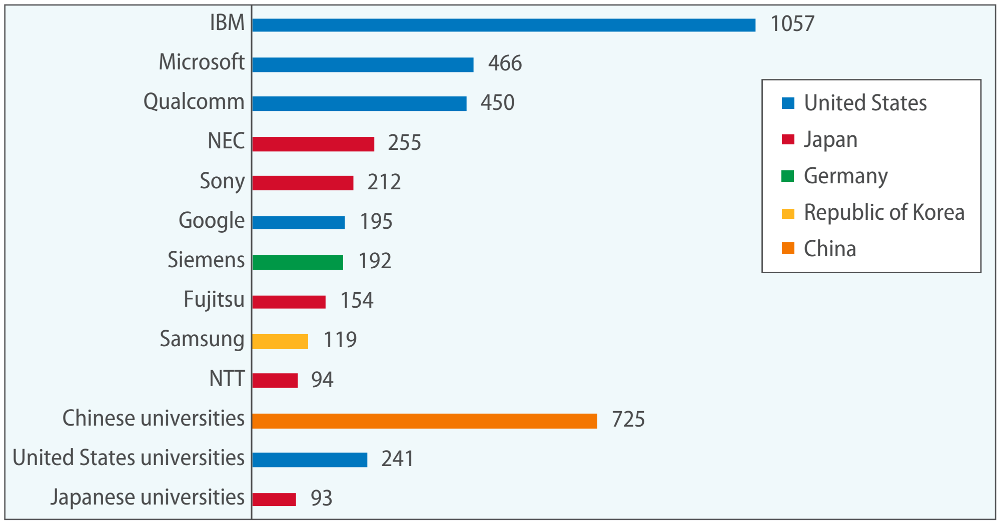
It is important to note that these processes are inextricably linked. For example, adoption of a new technology by a large group of users provides useful feedback to the innovators themselves (Jaffe, 2015). Further, broad diffusion keeps laggard firms from falling too far behind the leading firms as regards technological capabilities; and the resulting upward pressure exerted on both frontier and non-frontier firms in terms of their incentives to innovate supports innovation (Benhabib, Perla and Tonetti, 2017).

Linkages among actors in a national innovation system are central to a country's improvements in technology performance

The focus on the NIS is underpinned by the understanding that linkages among actors involved in innovation are central to improvements in technology performance (OECD, 1997). Such linkages are complex and the success of a country's innovation efforts relies on how those actors interact in generating and diffusing innovation. Traditional actors in the NIS include a myriad of private sector firms, universities, research institutes, think tanks, industry associations, advocacy groups, and government agencies and enterprises. They vary in size, engage in activities in different areas of technology and possess varied sets of capabilities.

Figure IV.4

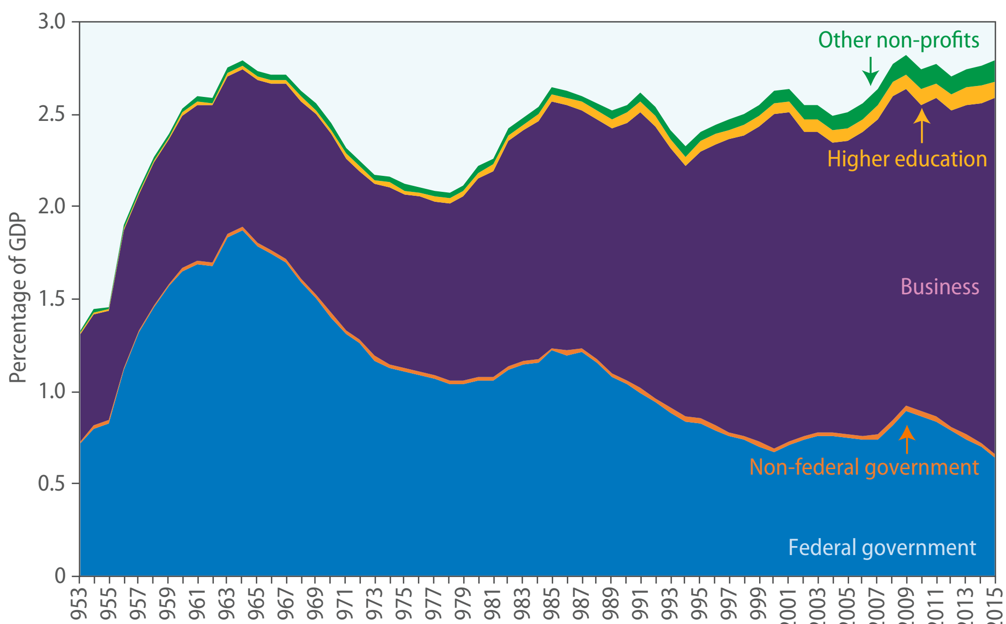
Number of AI patents granted, selected companies, 2010–2016



Source: Elaboration of Bruckner, LaFleur and Pitterle (2017), based on data from Fujii and Managi (2017).

Figure IV.5

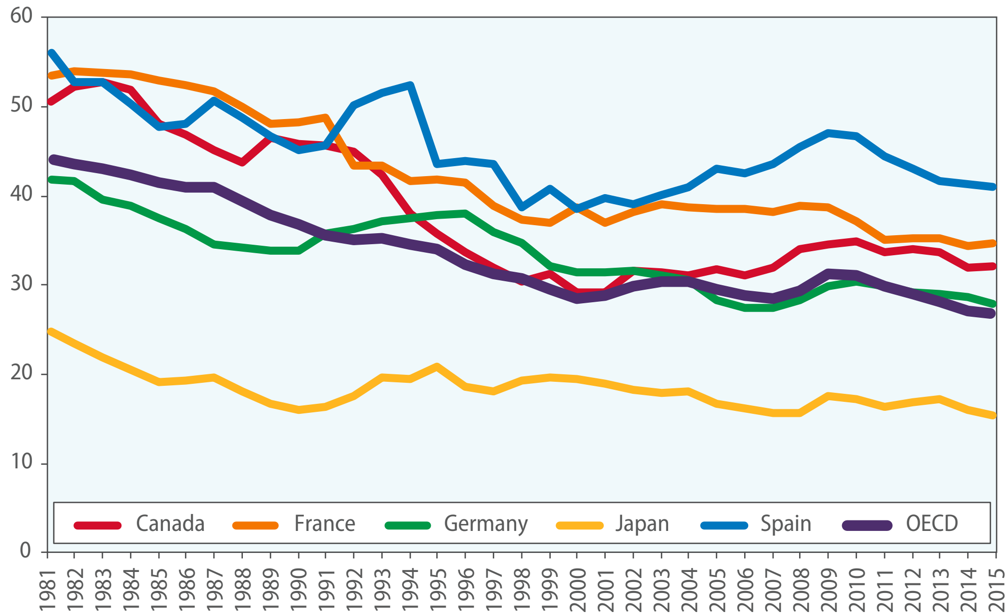
United States spending on R&D by source, 1953–2015



Source: Shambaugh, Nunn and Portman (2017).

In the current technological landscape, it would appear that the private sector has secured a dominant position, as it accounts for many of the advances achieved at the global technological frontier. For example, the latest advancement in AI around the world has been largely led by a small set of large technology companies (see figure IV.4). Moreover, in recent decades, R&D spending by the private sector has outpaced public sector spending, especially in developed countries (see figures IV.5 and IV.6).

Figure IV.6
Percentage of gross domestic expenditure on R&D financed by government: Canada, France, Germany, Japan, Spain and OECD, 1981–2015



Source: UN/DESA elaboration, based on OECD.Stat:Main Science and Technology Indicators.

The private sector's dominance in the current technological landscape masks Government's catalytic role in fostering innovation

However, the observed dominance of the private sector masks the catalytic role played by government in fostering innovation. Indeed, while one might attribute the success of the Apple iPhone or the Google search engine to the ingenuity of these private companies, Mazzucato (2011) argues that the emergence of some of these firms' innovative products would not have been possible without government support. For example, many of the key technologies that underpin the iPhone and similar smartphones—such as the Global Positioning System (GPS), the touchscreen display and the voice-activated personal assistant—were funded by the United States Government. As for Google, the creation of its search engine algorithm received government financial support through the United States National Science Foundation.[8] From this perspective, despite the private sector's dominance at the technological frontier, Governments play a catalytic—and indispensable—role in driving innovation. Playing such a role effectively, however, would require Governments to address market failures and shape the direction of future innovation by supporting the development of certain technologies at the initial stages, while acknowledging and mitigating their own limitations in respect of identifying the most promising technologies.

Moreover, the fact that some firms are leading global innovation activities does not mean that all firms are eminently capable of undertaking R&D. This is particularly true in developing countries where many firms do not have adequate resources to conduct in-house R&D and therefore face the prospect of highly uncertain returns should they engage in efforts to innovate (see figure IV.3; and Lee, 2013).

In addition, even firms that can engage in R&D do not always act to maximize their innovation potential. Instead of consistently carrying out optimal actions as they continue to gain access to new information, firms may follow certain culturally and historically

8 See "On the Origins of Google" at https://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=100660.

conditioned routines to enable them to manage that information, which could also limit their innovation efforts (Nelson and Winter, 2009). This highlights the importance of maintaining healthy market competition, as discussed in chapter V, which reduces barriers to entry and encourages the entry of new firms with modi operandi that are more suitable to the evolved technological landscape.

Another notable development in recent years, besides the rising dominance of the private sector in frontier technological advancement, is the emergence of so-called open science, which is defined as "the practice of science in such a way that others can collaborate and contribute, where research data, lab notes and other research processes are freely available, under terms that enable reuse, redistribution and reproduction of the research and its underlying data and methods".[9,10] With the emergence of open science, there has been increasing involvement of non-traditional actors, including smaller research groups and independent researchers, in complex innovation activities. This directly changes the dynamics within national innovation systems.

Further, if the currently nascent open science movement continues to progress and increase public engagement in innovation activities, it could also have an indirect, long-term impact on a country's innovation frontier through improving disadvantaged groups' exposure to innovation and expanding the pools of talent whose members could one day become inventors.[11]

Overall, the success of an NIS depends critically on how interactions among the expanding set of actors and rapid, non-linear technological changes are managed. A key consideration in the context of this national effort is how government policies can guide and incentivize national innovation systems based on a country's specific circumstances, as discussed below.

Supporting a balanced and dynamic national innovation system

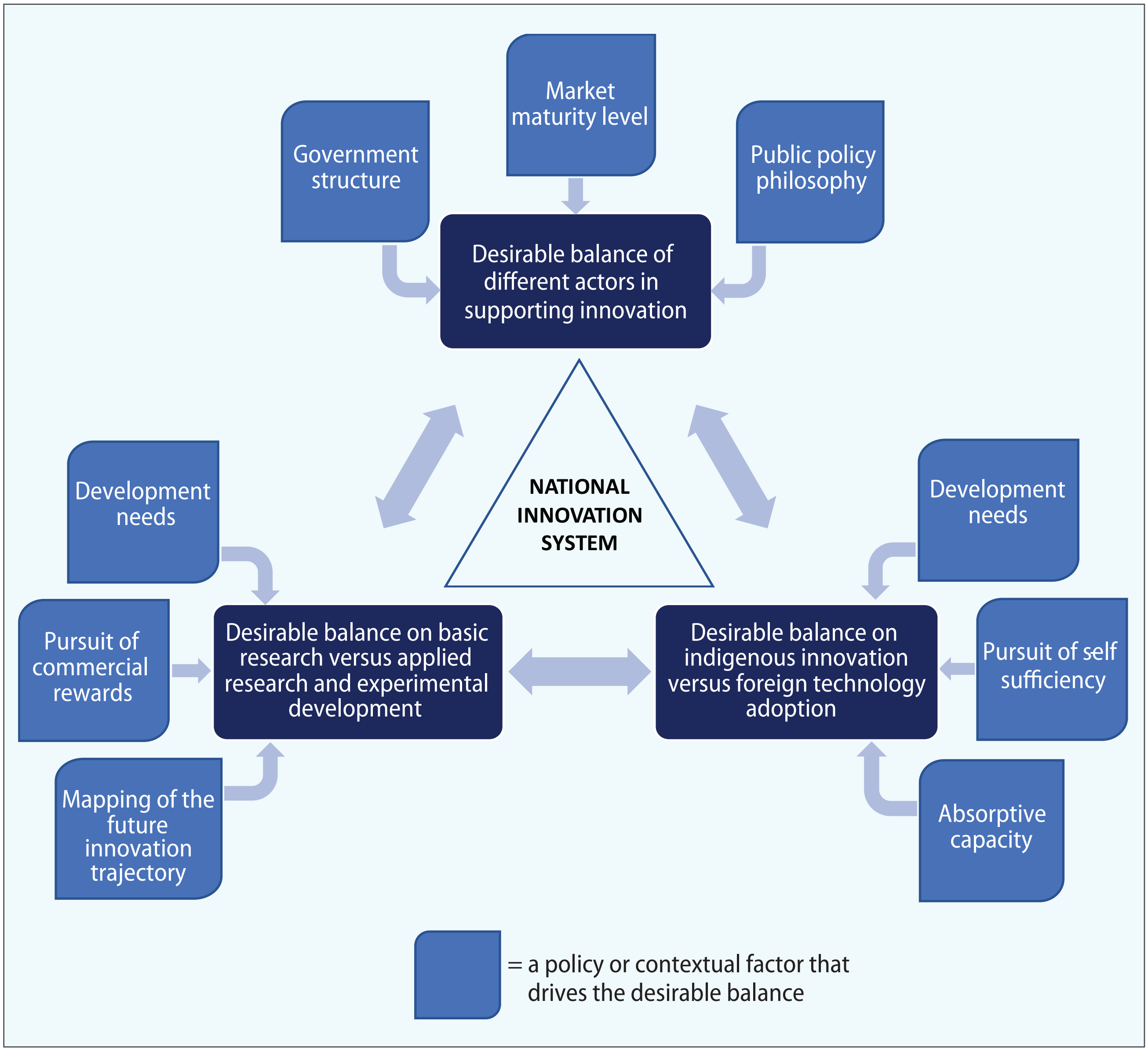
National innovation systems across the world typically differ in terms of three key systemic features: (a) balance among the various roles of different actors in supporting innovation; (b) balance between basic and applied research and experimental development; and (c) balance between indigenous innovation and adoption of foreign technology.

9 The definition has been formulated by FOSTER Plus (Fostering the practical implementation of Open Science in Horizon 2020 and beyond), which is a European Union-funded project, conducted by 11 partners across six countries. The project's primary aim is to contribute to a real and lasting shift in the behaviour of European researchers to ensure that open science becomes the norm.

10 For further discussions on open science, see UNESCO (2015) and Royal Society (2012).

11 Analysing data on 1.2 million United States inventors from patent records linked to tax records, Bell and others (2017) found that lack of exposure to innovation can help explain why children from below median income families are 10 times less likely to become inventors than those from families at the top 1 per cent income level, and why there are similarly large gaps among racial and gender groups. Exposure to innovation is defined as contact with someone who engages in innovation activities, for example, through one's family or neighbours. Bell and others (2017) measure such exposure by the patent rate among workers in one's commuting zone, i.e., the average number of patents issued per year to individuals in a given commuting zone between 1980 and 1990 divided by the commuting zone's population between the ages of 15 and 64 in the 1990 Census.

Figure IV.7
Balancing key systemic features of a national innovation system



Source: UN/DESA.

A country's capacity to strike the desired balances determines the functioning of its NIS, which in turn determines—especially in the case of a country at a distance from the technological frontier—whether it will be able to bridge the technological divide and achieve sustainable development. Through their awareness of country-specific development and institutional contexts which evolve over time, policymakers play a key role in guiding the innovation systems towards the desirable balance on each of the three fronts (see figure IV.7).

Striking desired balances on each of the three key systemic features of a national innovation system is central to bridging the technological divide

Balancing the roles of different actors in innovation

The nature of the relative balance among different actors in supporting innovation is one key feature of national innovation systems where differences exist. In the simplest terms, those systems can be placed along a private-public continuum, with state-led systems on one end and market-led systems on the other. A market-led NIS is characterized by R&D activities that are conducted mainly in anticipation of the expected return on innovation; and by innovation choices that are driven largely by the profit motive. Innovation decisions made in a state-led innovation system, on the other hand, are typically guided by the development issues addressed by Governments, such as economic growth, public health, environmental sustainability and national security.

China's public sector is directly involved in all facets of innovation...

Owing to their leading roles in global innovation efforts and their notable institutional differences, China and the United States have often been used to compare state- and market-led systems. China's public sector is directly involved in all facets of innovation, including definition of research objectives, engagement in actual R&D activities and provision of funding for innovation activities. The significant reach of the public sector in China's innovation landscape is enabled by a governance system characterized by a considerable degree of central planning and coordination, which gives the government the ability to develop a national strategic approach to technology development.

...while the United States Government plays a more indirect role

The United States Government, on the other hand, plays a more indirect role in supporting innovation at all levels — an approach that is underpinned by the tenet in economics that markets are more efficient at allocating R&D investments. The relatively indirect, and often imperceptible, involvement of government also reflects a wider distribution of institutional capabilities and responsibilities, which — together with the need for extensive coordination — prevents any single government agency from taking a leading role in driving national innovation policy (Melaas and Zhang, 2016).

Nevertheless, Melaas and Zhang (2016) argue that, even in the case where there is a well-recognized difference in the relative public-private balance in the NIS, the Governments of both China and the United States play an active role in supporting and influencing innovation activities of the private sector.

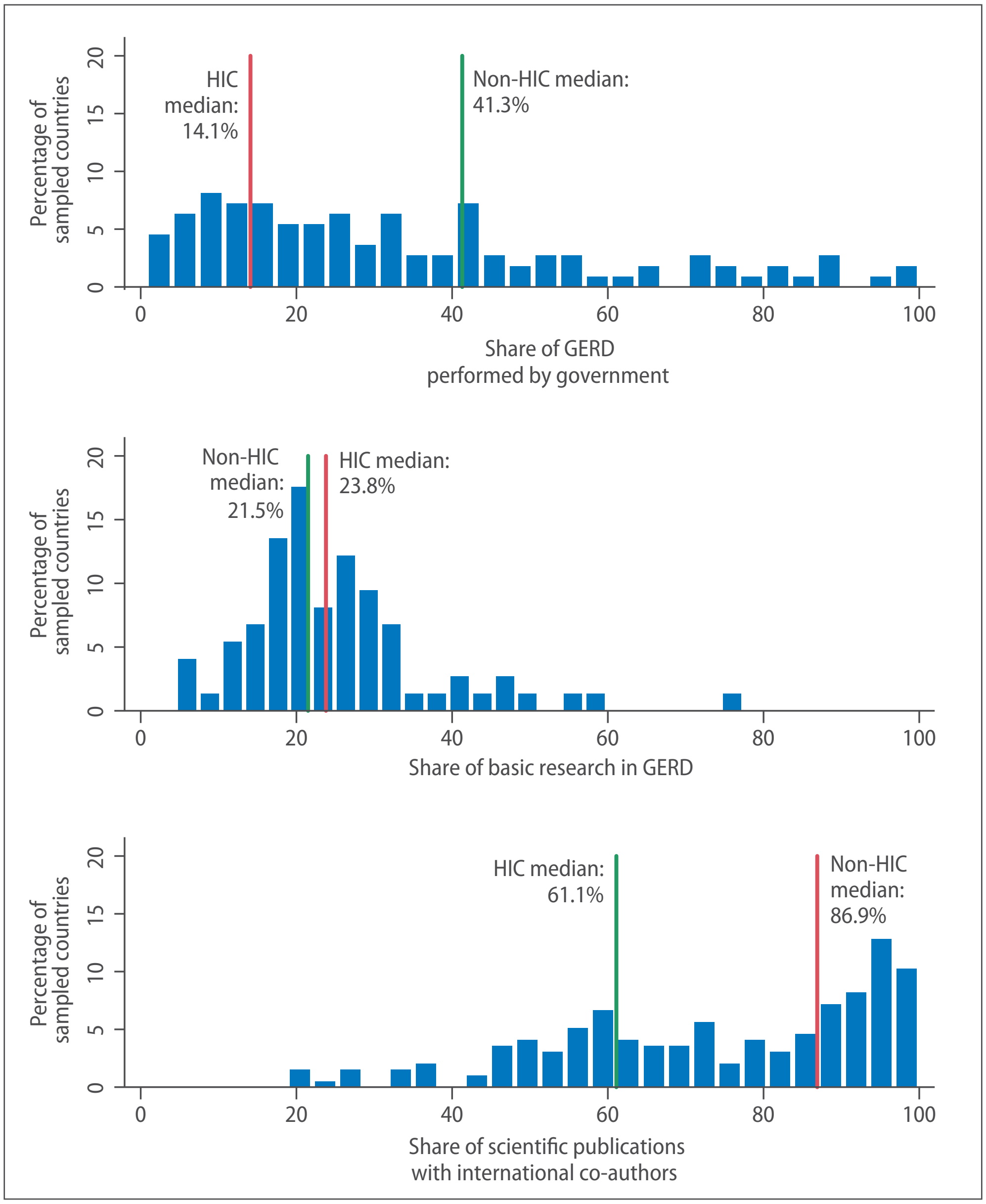
To a great extent, achievement of the desired balance among the roles of different actors in a country's NIS depends on its institutional arrangements, including government structure, level of market maturity and public policy philosophy, which evolve over time. Nevertheless, recent statistics suggest that governments in developing countries tend to play a more dominant role in R&D than their counterparts in developed countries (see figure IV.8), which likely reflects the lower levels of market maturity and of research capabilities of private firms in developing countries.

Creating a highly networked system of actors which facilitates knowledge flow and harnesses their collective innovation potential is most important

The most important goal of innovation systems is to create a highly networked system of actors which facilitates knowledge flow and harnesses the country's collective innovation potential. Mazzucato (2011) uses the experience of Japan in the 1970s and 1980s, compared with the contemporaneous experience of the Soviet Union, to demonstrate the importance of such linkages. Japan's Ministry of International Trade and Industry pushed for policies that centred on coordinating intra-industrial change, intersectoral linkages, inter-company linkages and the private-public balance. Further, in Japan, new knowledge flowed among ministries of science, academia and industry within a framework that was horizontally structured; in the Soviet Union, by contrast, business enterprises were not able to commercialize the knowledge developed by the State. The strong networks among key actors in its innovation system helped to sustain Japan in its quest to reach the global technological frontier.

Figure IV.8

Examples of cross-country variation in the three key systemic features of national innovation systems, 2008–2014 average



Source: UN/DESA, based on data from UIS.Stat and UNESCO (2015).

Abbreviations: GERD, gross domestic expenditure on research and development; HIC, high-income country.

Note: The figures are histograms, with each bar indicating the percentage of sampled countries that fall into the range of values where the bar is positioned. Sample size for share of GERD performed by government, for share of basic research in GERD, and for share of scientific publications with international co-authors are 111, 74, and 195 countries, respectively.

Balancing basic and applied research and experimental development

Another systemic feature of national innovation systems with respect to which there are divergences is the relative weight placed on basic and applied research and experimental development. The category of basic research is driven largely by a commitment to scientific enquiry and the desire to expand the knowledge frontier, without explicit consideration of the commercial value of the results of that research. The goal of applied research, on the other hand, is to find solutions to practical problems which, typically, improve development conditions. Experimental development entails systematic work, drawing from existing knowledge that is directed towards producing new products and services or improving existing ones.

Most countries, regardless of their development condition, spend substantially more on applied research and experimental development than on basic research (see figure IV.8). Nevertheless, there is still significant cross-country divergence. While the impression may exist that in general, developed countries spend more of their research budget on basic research, compared with developing countries, recent data suggest that the proportion of the research budget allocated to basic research in many developing countries is comparable to that for developed countries. This is reflected in the similar median shares of basic research in gross domestic expenditure on research and development (GERD) in high-income and non-high-income countries (23.8 versus 21.5 per cent, respectively) (see figure IV.8).

The United Nations Educational, Scientific and Cultural Organization (UNESCO) (2015) notes that in recent years, especially in the wake of the global financial crisis, the world has witnessed a shift away from investment in basic research, as countries focus on the commercial rewards to be reaped from scientific activity and the relevance of scientific discovery to solving pressing development challenges.

The desired balance among resource allocations to different research categories depends largely on a country's development needs and its desired innovation trajectory

The desirable balance among the resources allocated to different research categories is mainly a function of a country's development needs and its desired future innovation trajectory. On the one hand, applied research and experimental development produce results that are immediately applicable and yield commercial rewards, which are important for advancing development in the short run. On the other hand, basic research is essential for future scientific discoveries and has often been the driver of the immense progress made in deriving applications for those discoveries. For example, identification of the 25,000 genes in human DNA—driven by scientific curiosity—paved the way for work on the sequencing of the nucleotide base pairs in the human genome which has practical, material implications for the treatment of genetic diseases (UNESCO, 2015). Further, engagement in basic research activities—typically carried out by academia and public research institutes—contributes to an improvement in the quality of higher education, which in turn helps to nurture innovation talent. Therefore, any country that wishes to produce frontier technologies cannot do so without enabling basic research.

Singapore illustrates how an NIS can shift its balance between basic and applied research according to evolving development needs (Wong and Singh, 2008). Singapore's innovation system was, in its early years, heavily skewed towards applied research, which proved critical for the success of its industrial clusters. However, once Singapore sought to operate in more knowledge-intensive industries, such as the life sciences and advanced materials industries—industries where the knowledge often remains highly concentrated in regional innovation clusters in advanced economies—the Government began to put a stronger emphasis on basic research. It was hoped that such a shift would allow the country to acquire more durable competitive advantages.

Balancing indigenous innovation and adoption of foreign technologies

National innovation systems also differ in terms of the relative emphasis that they place on indigenous innovation versus foreign technology adoption. This reflects specifically how much a country relies on foreign support in advancing its own technological development, through, for example, importing foreign technologies or collaborating with foreign researchers. Knowledge obtained through interactions with foreign partners can be products of basic research, applied research or experimental development.

Developing countries tend generally to rely more on foreign technology adoption for technological development, given that innovation is costly, risky and path-dependent (Fu, Pietrobelli and Soete, 2011). Developing countries' stronger reliance on foreign technological knowledge is also reflected in their typically higher share of scientific publications with international co-authors (see figure IV.8).

A country's absorptive capacity and actual development needs are equally important in determining its desirable level of reliance on foreign technologies

However, empirical findings regarding countries' gains from international knowledge transfer offer a mixed picture.[12] The inappropriateness of foreign technology in local contexts is a key reason why the evidence is not always uniform. The results suggest that a country's indigenous innovation is at least as important as foreign technology adoption, as it fosters development of absorptive capacity by improving human capital and encouraging R&D activities.[13] This leads to an important observation: To what extent a country should rely on foreign technologies depends as much on its absorptive capacity as on actual development needs.

The experiences of China and India—both populous developing countries and major originators of international patent applications—provide contrasting examples of how this balance can be pursued. While India has emphasized promotion of foreign technology adoption in specific sectors such as information and communications technologies (ICT), China, generally, has been relatively more active in its efforts to enhance the capacity of the domestic science and technology sectors (Crescenzi and Rodríguez-Pose, 2017). Still, despite this difference in overall emphasis, the remarkable growth of the solar photovoltatic (PV) industry in both countries illustrates the importance of the proper use of mixing and sequencing mechanisms of indigenous innovation and international technology transfer (Fu and Zhang, 2011).[14]

Interdependence of the three systemic features

The three key systemic features of a national innovation system are often interdependent and mutually reinforcing

Striking desirable balances on all three fronts is further complicated by the fact that these features are often interdependent and mutually reinforcing. Efforts by policymakers to guide a country's NIS towards a certain mix on one front could be undermined by efforts on the other two fronts, if they are incompatible. For example, a country that seeks to move towards an indigenous innovation-oriented innovation system would need to engage in commensurate efforts towards promoting basic research, if it hopes to move towards the global technological frontier. This also means that universities and public research

12 See Görg and Strobl (2001), Blomström and Kokko (1998), and Meyer (2004) for excellent surveys of the literature on spillovers from foreign direct investment.

13 Here, absorptive capacity is defined as "a set of organizational routines and processes by which firms acquire, assimilate, transform, and exploit knowledge to produce a dynamic organizational capability" (Zahra and George, 2002).

14 Most leading solar PV companies in both countries complement their international technology transfer by increasing investment in indigenous R&D activities, which has helped to facilitate foreign technology adoption and indigenous technological capability development. Once basic technological capabilities were established, these firms went on to engage in more active technology acquisition and creation through both indigenous innovation and international R&D collaboration. Their successful experience demonstrates the importance of employing the right combination of international technology transfer and indigenous innovation.

institutes, typically the primary undertakers of basic research, would need to achieve greater prominence in the national innovation landscape.[15] Commensurate investments in the education system, beginning with the primary and secondary education levels, would also be required.

On the other hand, a country that seeks to focus on foreign technology adoption should ensure that firms—especially those operating in trade sectors and/or with some foreign ownership—play a more important role, given that international technology transfer occurs largely through trade and foreign direct investment (FDI). At the same time, institutions that facilitate active technology diffusion need to assume a stronger role in the innovation system as well.[16] A stronger emphasis on foreign technology adoption would also likely entail a stronger national focus on applied research and experimental development relative to basic research.

The current technological landscape is marked by rapid changes and convergence of different areas of technology

Last, the current technological landscape is marked by rapid changes and convergence of different areas of technology. As noted by Schwab (2016), the current rapid technological change is characterized by "a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres". The rapid pace and complexity of technological advancement will determine the desirable country-specific balance among these factors.

As technologies have become increasingly complex and the uncertainties associated with their development and adoption have increased considerably, stronger government support is required to help firms and research institutes weather related risks. To compete in this technological landscape, firms will need to access new technologies from both within and outside their traditional competency networks. Countries—especially developing ones—will perceive that their need to maintain an effective channel for introducing technologies from overseas is greater than ever.

A survey conducted by Larsen, Ahlqvist and Friðriksson (2009) on Nordic firms has shown that even those in advanced national innovation systems experience difficulties in identifying new partners from outside their traditional networks and subsequently in achieving convergence of different technologies. The survey highlights the importance of stronger involvement of mediating organizations, such as universities, science parks and sector organizations, which can help firms reduce their search costs.

Macroeconomic determinants of the efficacy of a national innovation system

Enabling regulatory frameworks and complementary infrastructures are crucial in generating incentives for innovation

Any efficiently functioning NIS, regardless of its broad systemic features, requires an enabling environment which provides sufficient incentives for innovation. Several macroeconomic factors are particularly crucial in influencing such incentives and driving the efficacy of a nation's innovation process.

15 Switzerland, a world-class leader in innovation which spends a high proportion of its research budget (30 per cent) on basic research, has illustrated the advantage of establishing a clear division of labour between the public and private sectors, with the public sector playing the leading role in non-oriented basic research and the private sector focusing on translation of scientific breakthroughs into competitive products (UNESCO, 2015).

16 Elaboration of the role of those institutions will be found in a subsequent discussion on the challenges faced by NIS in their efforts to catch up and keep up.

One key factor is market competition. For every technology market, there is a market-specific optimal level of competition for incentivizing innovation.[17] On the one hand, firms may not be sufficiently incentivized to innovate if there is little competition. On the other, too much competition could discourage firms from innovating, as intense competition reduces the expected profits resulting from innovation. Lower profit also reduces the room for firms' investment in R&D activities.

An appropriate level of antitrust regulation must be in place to ensure that there is a level playing field for technology developers and to promote market entry. Intellectual property regulation is another important part of the overall regulatory framework, as it determines the trajectory of national innovation endeavours. Too little intellectual property protection, without alternative mechanisms to compensate innovators, can discourage innovation. On the other hand, overly stringent intellectual property protection can also hamper innovation, as it constrains knowledge flow. Further, regulation — for example, on consumer protection and privacy — is central in ensuring that the direction of technology development will improve social welfare and that such improvements will be shared equitably across the population.

Another key component of the NIS is complementary infrastructures (whose importance has been detailed in chapter III), which include technical facilities, legal and business services, and telecommunication and transportation infrastructure.

Innovators face different financing needs and interact with different financial intermediaries at various stages of product development

From a broader perspective, infrastructure also includes the all-important financial infrastructure, encompassing payment systems, insurance services, credit information bureaux and collateral registries. These infrastructures are crucial to the effective operation of the various financial intermediaries that can support innovation. Depending on the stage of their product development, entities engaged in innovative activities would experience different financing needs and would therefore need to interact with different financial intermediaries (United Nations, Economic Commission for Europe, 2009).

At the early stages of product development, when there is a high risk of failure, innovative entities need access to forms of financing that do not entail guaranteed repayment. These include merit-based awards and infusion of external equity which allows investors to monitor the functioning of the business and exercise significant control over it in order to manage the downside risk of their investment. Whereas merit-based awards are often provided by public agencies, external equity typically involves angel investors, seed funds and venture capital funds. More recently, crowdfunding has also emerged as an alternative financing source for early-stage innovative activities (Agrawal, Catalini and Goldfarb, 2014).

However, traditional financial intermediaries such as bank lenders and stock markets become more important as the innovative activities move into the later development stages and require additional financial resources.

Challenges faced by national innovation systems in keeping up and catching up

Successful national innovation systems are typically characterized by a strong knowledge base, a well-functioning market system and developed institutions and infrastructures

17 Market competition is typically measured by market share, price-cost margin or the Herfindahl concentration index.

which support innovation activities. However, concerted effort is still required to maintain the competitiveness of those systems for at least two reasons. First, the market institutions and infrastructures can deteriorate. Second, as the global technological landscape evolves rapidly, leading national innovation systems could find themselves hindered by what has now become legacy infrastructures and institutions (although they had previously served the systems well).

For example, legacy information technology (IT) infrastructure which cannot process a large amount of unstructured data with high speed could hamper considerably the development of AI technologies. Further, as will be elaborated in chapter V, the rise of big data and algorithms are significantly changing the nature of competition dynamics, which poses regulatory challenges. Within this context, the key challenge for the leading national innovation systems in adapting to the evolving technological landscape is therefore to continue investing in the latest infrastructures and refining institutional arrangements.

Laggard national innovation systems face a more pressing need to account for every factor that influences physical, human and knowledge capital accumulation

National innovation systems that are far away from the global technological frontier, on the other hand, are facing a different set of challenges in their effort to catch up with the technological leaders. Cirera and Maloney (2017) argue that the scope of the national innovation systems that must be taken into account by policymakers in developing countries is much larger than the scope of those in advanced economies. In developing countries, the need is more pressing to account for every factor that influences the accumulation of physical, human and knowledge capital and the institutions and markets that support such accumulation, including education systems, financial markets and trade agreements.

In reality, many developing countries still have weak institutional structures for supporting innovation. Their innovation systems tend to be highly fragmented, with a large number of small enterprises, an often overcrowded public sector support system which fails to provide sufficient technological support services and infrastructures, and a limited research community which is not well connected to development realities (Aubert, 2005).

At the same time, many developing countries—which typically experience faster economic development—require higher adaptability of their innovation systems (Varblane, Dyker and Tamm, 2007). Furthermore, FDI in developing countries is playing a more important role than in the developed countries, which means that the globalization process is exerting a stronger influence on the development of innovation systems in developing countries. Improving institutional and infrastructure quality of laggard NIS is therefore imperative.

Countries also need to ensure that the development of high-tech industries does not occur at the expense of support to medium- and low-tech industries, which typically account for a much larger share of employment and output (Varblane, Dyker and Tamm, 2007). Rather, development of high-tech industries must be complementary to that of the medium- and low-tech group. Indeed, technological advances achieved in the high-tech industries should enhance the competitiveness of medium- and low-tech industries.[18] Conversely, the application of advanced technologies in medium- and low-tech industries can provide feedback to the high-tech industries and further technological development.

A key effort required for the support of industries at the early stages of innovation is the building up of firms' managerial and organizational capabilities, which are crucial for effective management of innovative activities (Cirera and Maloney, 2017). Firms in

18 The wood and paper industry in Finland—a small open economy—offers an example of how international competitiveness can be achieved through use of high-tech technologies in different segments of mature medium- and low-tech industries (Viitamo, 2003).

developing countries typically lag behind those in developed countries in the acquisition of such capabilities, which cover, inter alia, the capacity to take a long-term view, project evaluation skills, and a human resources policy designed to assure the presence of staff for R&D projects.

It is crucial for laggard national innovation systems to develop a model for active management of technology diffusion

It is equally important for laggard national innovation systems to develop a model for active management of technology diffusion. Successful experiences of economies of East Asia in earlier phases of technological development—when they lacked resources and advantages other than temporary cost advantages—have demonstrated the importance of development of a network of institutions for technology diffusion and organizational management (Mathews, 2001).

Institutions such as public sector laboratories, developmental consortia and well-established national firms were tasked with accelerating the private sector's technology uptake. They identified the technological knowledge and related resources that were most readily available for leveraging by firms in support of industrial development. This was important, as firms tend to be myopically focused on the search for knowledge and solutions within their existing competency neighbourhood (Fagerberg and Godinho, 2006). The support provided by these institutions meant that firms could channel their energies into transforming innovations into technological capabilities and competitive products.

Drivers of diffusion in an interconnected technology landscape

Previous discussions on the innovation systems of East Asian economies have demonstrated that diffusion plays a central role in advancing a country's technological development. Diffusion is also crucial for the materialization of broad development impacts of new technologies, both those generated domestically and those generated beyond borders.

Diffusion is arguably more important than innovation in closing the technology gap between and within countries. From an allocative efficiency perspective, one could argue that innovation gaps of a certain magnitude between and within countries are acceptable or even desirable, considering that countries, firms and individuals vary in terms of their innate innovative capacity. What truly matters when it comes to ensuring equitable sharing of benefits ushered in by frontier technologies is that these technologies, once created, be accessible to and adoptable by the broader population.

Cross-border technology diffusion: international trade and investment and a global IPR regime

Effective cross-border technology diffusion is central to closing the between-country technological divide, as discussed in chapter III. The existing literature generally focuses on international trade and FDI as two key international technology transfer channels.

International trade and foreign direct investment are two key channels for international technology transfer

International trade is a key technology diffusion channel from both the exporter and the importer perspectives. On the one hand, firms can acquire new technologies that are embedded in intermediate goods and capital equipment via importing from foreign firms. On the other hand, firms could also learn by exporting, through interactions with their overseas customers, although this transmission channel appears to be a weak one (Keller, 2004). As regards the key channel of FDI, the strength and speed of technology transfer depend on the ownership structure of the firms that receive such investment and the extent of interaction between the receiving firms and the rest of the domestic economy.

International technology cooperation is a complementary channel

International technology cooperation is yet another technology transfer channel. Recent establishment of the Technology Bank, first proposed in paragraph 52 (l. Joint actions) of the Programme of Action for the Least Developed Countries for the Decade 2011–2020;[19] and the launching of the Technology Facilitation Mechanism, in the 2030 Agenda for Sustainable Development[20] under Sustainable Development Goal 17.6, are among the international community's latest efforts to strengthen international cooperation on science, technology and innovation. Facilitation of technology transfer is a key objective under both mechanisms (United Nations, 2017c).

The efficacy of international technology transfer is influenced by the global IPR regime and trade and investment agreements

The efficacy of these international technology transfer channels is influenced by several factors, notably the global IPR regime and the complex web of multilateral, plurilateral and bilateral trade and investment agreements. In practice, multilateral, plurilateral and bilateral trade and investment agreements often have specific IPR components, making them important components of the global IPR regime.

While IPR are crucial in ensuring that innovators can properly benefit from their creation, they are also capable of creating obstacles to legitimate trade, thereby weakening a key international technology transfer channel (Kamperman Sanders, 2018).

Only a harmonized level of IPR protection could ensure a level playing field in international trade. Gaps in the scope of IPR protection and enforcement would lead to trade distortions and disrupt international technology transfer. As for the role of IPR in attracting FDI and facilitating technology transfer, empirical evidence has presented a mixed picture, as the relationship between IPR and FDI in developing countries appears to vary by industry, the level of economic development and the policy environment of the host country, and the mix of natural resources and human capital.

Overall, existing studies on international technology transfer have suggested that human capital levels, the historical path of technology adoption, institutions and policies, geographical proximity of countries, and aggregate demand for new technology are key factors in explaining cross-country differences in technology adoption (Comin and Mestieri Ferrer, 2014).

While higher levels of human capital are generally associated with higher levels of technology adoption, it is important to note that this trend varies across different technologies. For example, Comin and Hobijn (2004) found secondary school enrolment has a strong positive association with adoption of mass communication technologies, but not with adoption of other technologies—such as those used in textile and steel industries—that are less skill-intensive.

Past trends in technology adoption have been revealed to be another important determinant of technology adoption. Comin and Hobijn (2010) found that the observed persistence in technology adoption—i.e., the notable positive association between adoption of old technologies and subsequent adoption of new ones—is most likely driven by the accumulation of sector-specific technological knowledge. Such knowledge, generated by firms through their adoption and use of technologies across time, enables new technologies that are used in their specific industries to be adopted more easily.

19 *Report of the Fourth United Nations Conference on the Least Developed Countries, Istanbul, Turkey, 9–13 May 2011* (A/CONF.219/7), chap. II.

20 General Assembly resolution 70/1.

Besides a harmonized and flexible global IPR regime, enabling institutions are also central to faster diffusion of new technologies. Comin and Mestieri Ferrer (2014) argue that without proper institutions to protect technology adopters' rights over their technologies or the income that they generate, firms, households or individuals might be deterred from investing in and adopting new technologies. Moreover, a lack of inclusive institutions may allow political or economic incumbents—whose economic or political rents are threatened by new technologies that broadly reduce transportation and communications costs—to lobby for the creation of barriers that hamper technology diffusion (Acemoglu and Robinson, 2000).

Other studies have found that geographical proximity and the levels of aggregate demand to be notable drivers of technology adoption. With regard to geographical proximity, it is argued that technology tends to be more easily transmitted between firms or individuals in countries that are closer to each other, given that technology adoption requires knowledge which is often derived from interactions with others and that the frequency of those interactions is typically influenced by such proximity (Comin and Mestieri Ferrer, 2014). As for the role of aggregate demand, Comin and Mestieri Ferrer (2010) found that technology adoption is sensitive to movement of business cycles, suggesting that higher aggregate demand is associated with faster technology diffusion.

Determinants of adoption behaviour

The process of devising policies that facilitate technology diffusion can be aided by a sound understanding of what determines technology adoption behaviour

Policies can facilitate technology diffusion if they have been devised with a sound understanding of the determinants of the adoption behaviour of individual firms, households and individuals. This accords with the view of Shankar and Foster (2016) who, in their capacity as Behavioural Science Advisers to the United Nations, emphasized the cruciality of understanding people's behaviours in achieving the 2030 Agenda.[21]

The existing economic literature generally supports the view that the process of technology diffusion is the cumulative result of a series of individual calculations which weigh the net benefits of adopting a new technology, subject to limited information, uncertainty and financial constraints, against those of using existing alternatives.

In seeking to explain levels of demand for new technologies that are lower than the levels that standard cost-benefit analysis alone would predict, contributors to the more recent literature have examined the role of intra-household or intra-firm externality in decision-making (Miller and Mobarak, 2013; Atkin and others, 2017). This refers to the inability of the member of a firm or household who has control over purchasing decisions to take into account potential benefits and costs accruing to other members in the same household or firm from use of a certain product.

Another set of contributors to the emerging literature use insights derived from behaviourial economics to explain technology adoption behaviours. These insights reveal that people's behaviour is shaped by habits, inclinations and frequent disjunctions between intentions and actions (Brown, Zelenska and Mobarak, 2013). Moreover, heuristics, or information-processing rules that reflect a departure from full rationality—associated with, e.g., loss aversion, mental accounting, present-biased preferences and low self-control—

21 Increasing emphasis on such human behaviour-centred approaches can also be seen in a number of countries and international organizations that launched initiatives seeking to leverage behavioural insights to address policy challenges (see, for example, Behavioural Insights Team (2016) and World Bank (2015)).

also help to explain why it may be difficult for firms and households to invest in potentially profitable technologies.[22]

Thaler (1999) presents evidence demonstrating that loss aversion—i.e., a greater sensitivity to losses than to gains—plays an important role in individuals' financial decision-making. Such an aversion could reduce technology adoption below levels supported by rational cost-benefit analyses. He also argues that mental accounting—a set of cognitive operations used by individuals to mentally organize and evaluate financial activities—influences financial decisions in ways that violate the economic principle of fungibility. For those individuals who engage in mental accounting, money that has been reserved for or "saved" in one mental account cannot be easily transferred to another such account. This suggests that individuals may be more incentivized to save enough for investment in technology adoption if they have in mind a highly specific technology in which to invest (i.e., if they have opened a dedicated mental account), whereas individuals may be under-incentivized if they have only a vague intention of saving for future adoption of some yet-to-be identified technology.

In addition, the tendency of individuals to value current over future consumption (which illustrates a present-biased preference), or their inability to always act rationally in their own best interest (which illustrates the low self-control problem), makes it more difficult for them to invest in the adoption of welfare-improving technologies.

Rising importance of social and economic networks in technology diffusion

One subject that in recent years has received increasing attention in the economics literature is the role of social and economic networks (e.g., networks of firms and households) in technology diffusion. The interest in such networks, reflecting the economic, social and cultural constructs of a society, is motivated primarily by two factors.

The first is "technology externality" (also commonly referred as "network effect"). The term means that the value of a new technology is influenced by the extent to which it is adopted by others, either because the technology is used to facilitate interaction with others (e.g., the telephone, email or social media platforms) or because the provision of supporting facilities for the technology depends on the size of the user community. The second factor is the pervasive role of social and economic networks in influencing the spread and assessment of technology information, particularly through social learning (Wolf, Just and Zilberman, 2001; BenYishay and Mobarak, 2015).

Growing interconnectedness of technology decisions and increasing complexity of technology have made the role of networks in technology diffusion more salient

It can be argued that the current technological landscape has made examination of technology diffusion from a network perspective more relevant than ever. In particular, there are three developments that could currently justify a stronger emphasis on the role of networks in technology diffusion. First, the rise of social media and the Internet of Things has led to the growing interconnectedness of the technology-related decisions of firms, households and individuals and the impacts of those decisions. People are now increasingly aware of and influenced by other people's decisions, including their choice of technology.

Second, the increasing complexity of technology has been accompanied by the explosion of availability of technological information in the public domain. As a result of

22 For detailed discussions on these heuristics, see Thaler and Sunstein (2008).

this phenomenon, firms, households and individuals have been encouraged to rely even more on their networks to obtain, verify and process information on new technologies. Indeed, empirical evidence has shown that the pursuit of social learning is more evident within the context of the adoption of complex technologies (Liverpool-Tasie and Winter-Nelson, 2012; Oster and Thornton, 2012).

Third, there is an unevenness in technology diffusion which makes the study of diffusion patterns and their driving factors a critical task. The technology diffusion literature has traditionally focused on linking differences in technology adoption behaviour to the heterogeneous characteristics and preferences of firms, households and individuals. For example, the existence of the technological divide across countries is often attributed to differences in their innovative and absorptive capacities.

While capacity differences are certainly a key factor in this regard, it may not fully explain differences as related to technology adoption. The analytical work of Bala and Goyal (2001), for example, demonstrates that in a setting where agents are divided into different groups with more direct information links among agents within the same group as compared with links across different groups, technologies with different pay-offs can be adopted by agents in the long run even if they all have the same preferences and start off with the same beliefs.

This suggests that in an environment where there are different communities within a population, it is possible for one group to adopt a superior technology while another group converges towards adoption of an inferior one, even if the two groups are similar in terms of, e.g., educational levels and initial technological capacity. This can occur when all agents have incomplete information on new technologies and must learn about them from observing the technology choices of others. It can lead to cycles of social reinforcement which eventually push the group towards long-term adoption of a particular technology even if that technology does not represent the best option. These results explain the role that formal and informal networks play in technology diffusion, within the context of between- and within-country differences.

Policy challenges for bridging the technological divide

Previous sections discussed key features of, and enabling factors associated with, technology innovation and diffusion processes. Differentiated progress in the development of these processes leads to differentiated access to and adoption of technologies, resulting in the technological divide.

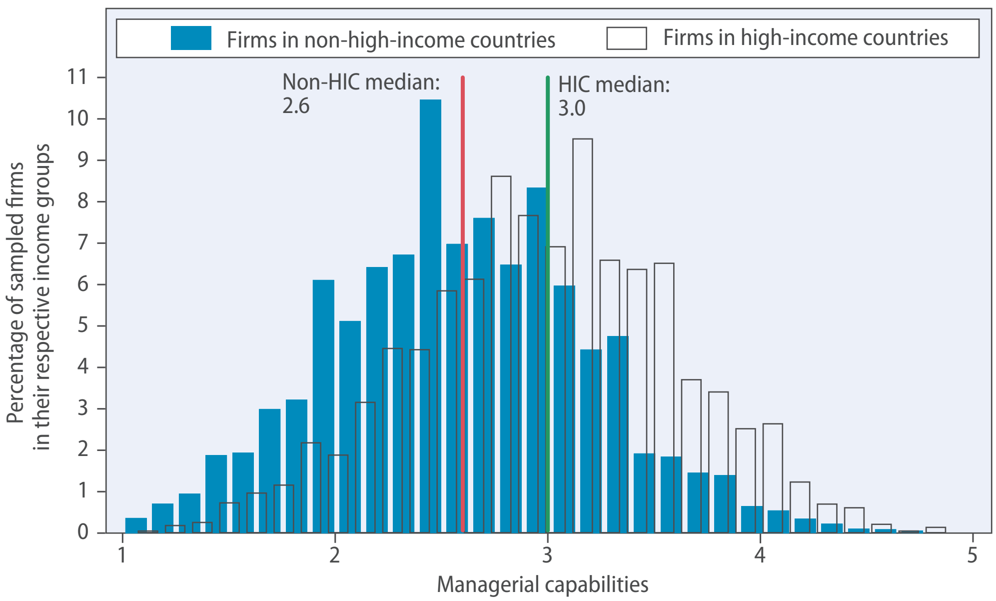
Continuing challenges: divergence of innovative and absorptive capacity

Continued divergences in innovative and absorptive capacities could further widen the technological divide

The continued divergences in innovative and absorptive capacities could contribute to a further widening of the technological divide. This is clearly displayed by the significant divergences across firms worldwide in terms of managerial capabilities, which are a critical facet of firms' overall innovative and absorptive capacity (see figure IV.9). Such divergences reflect the significant discrepancy in a number of underlying drivers, including human capital, complementary infrastructures, institutional quality and financial access (see, for examples, figures IV.10, IV.11 and IV.12 and the discussions in chap. III).

Figure IV.9

Distribution of firm-level managerial capabilities, high-income and non-high-income countries, 2004–2015



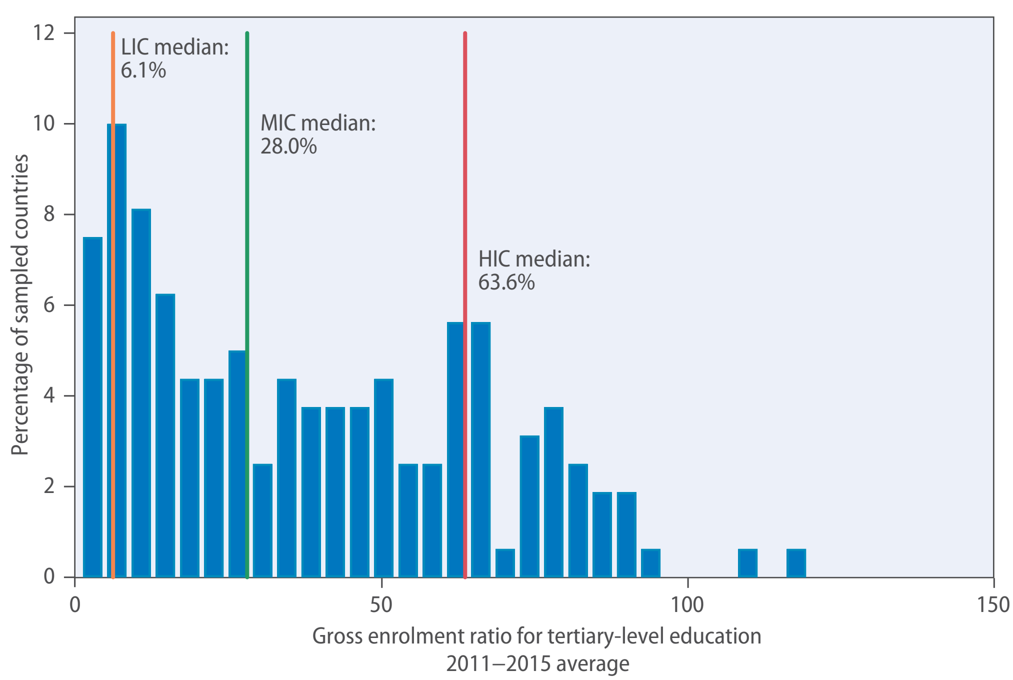
Source: UN/DESA, based on World Management Survey.

Abbreviations: HIC, high-income country.

Note: Managerial capabilities are scored from 1 to 5, with 5 representing the highest level. For further information on the World Management Survey, see Bloom and Van Reenen (2007). This sample includes 6,760 firms within high-income countries and 4,942 firms within non-high-income countries. Data on these firms were collected for various years over the period 2004-2015. The difference in the respective medians of the two country groups was found to be statistically significant, after a comparison of the Bonett-Price 99 per cent confidence intervals for the two medians.

Figure IV.10

Inequality in tertiary education levels, high-, low- and middle-income countries, 2011–2015 average

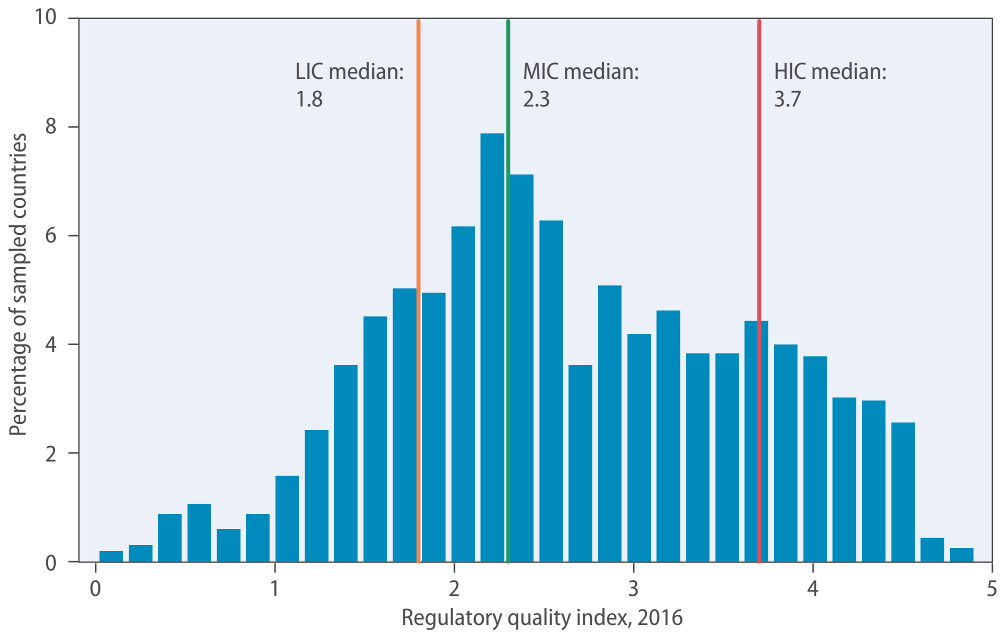


Source: UN/DESA, based on World Development Indicators.

Abbreviations: HIC, high-income country; LIC, low-income country; MIC, middle-income country.

Note: The figure is based on a sample of 160 countries.

Figure IV.11
Differences in perceptions of regulatory quality, high-, low- and middle-income countries, 2016

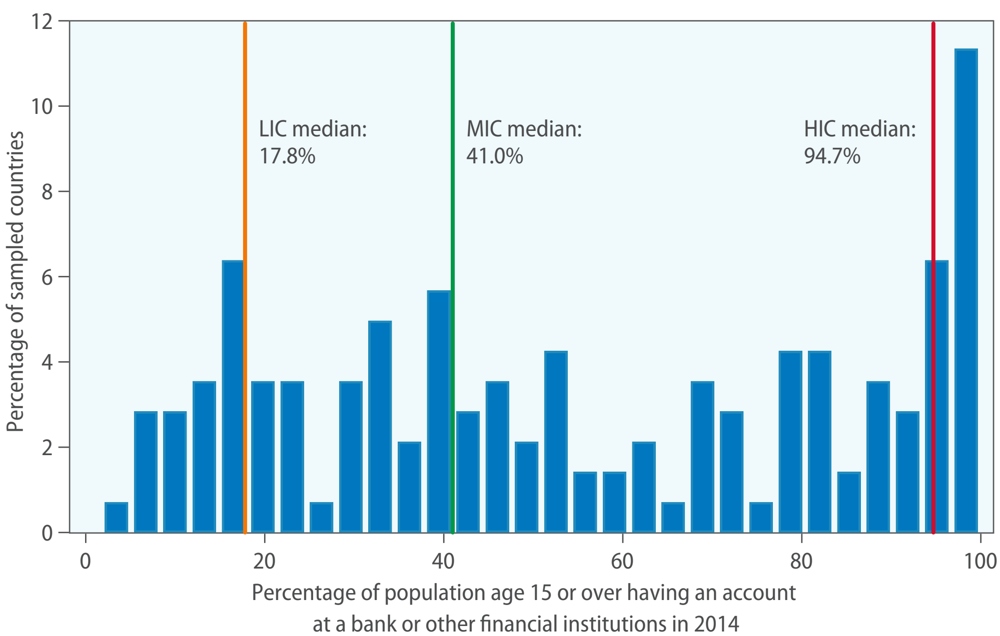


Source: UN/DESA, based on Worldwide Governance Indicators.

Abbreviations: HIC, high-income country; LIC, low-income country; MIC, middle-income country.

Note: The figure is based on a sample of 204 economies. The regulatory quality index captures perceptions of Governments' ability to formulate and implement sound policies and regulations which promote private sector development. The original regulatory quality estimates were rescaled, so that the values range from 0 to 5, with 5 denoting the highest regulatory quality. For further information on the World Governance Indicators, see Kaufmann, Kraay and Mastruzzi (2011).

Figure IV.12
Inequality in financial access, high-, low- and middle-income countries, 2014



Source: UN/DESA, based on data from Global Findex database.

Abbreviations: HIC, high-income country; LIC, low-income country; MIC, middle-income country.

Note: The figure is based on a sample of 159 countries.

Emerging challenges: market concentration, the IPR regime and networks

Rising market concentration, stringent IPR regimes and the rising salience of networks in technology diffusion pose challenges for narrowing the technological divide

In addition to the consistent divergence in innovative and absorptive capacities, three factors present increasing policy challenges for fostering innovation and narrowing the technological divide.

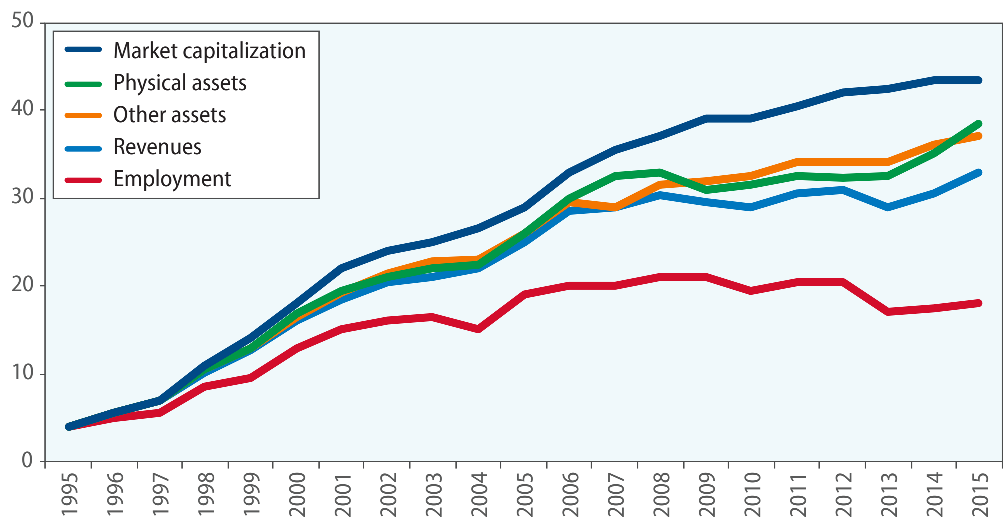
The rising concentration of market power around the world, with the software and IT services sector being one of the most concentrated industries (see figure IV.13), presents a significant challenge to future innovation and diffusion. Concentration of market power in a few firms allows them to engage in anticompetitive behavior which limits the innovation activities of other firms, hence creating an innovation gap.

The market competition landscape is further complicated by the emergence of big data and algorithms. Ezrachi and Stucke (2016) argue that, while big data and algorithms provide extremely valuable benefits, they can also potentially harm competition in several ways, including through allowing firms to use de facto data ownership as a barrier to entry, facilitating collusion among firms, enabling dominant firms to quickly detect and eliminate nascent competitive threats, and raising consumers' switching cost in an era where the quality of digital services increasingly relies on the personal information possessed by a service provider. Chapter V discusses the implications of emerging technologies for market competition and antitrust regulation.

Another development that could serve as an obstacle to narrowing the technological divide is the increasingly stringent IPR regime. Baker, Jayadev and Stiglitz (2017) have argued that the current regime is not well aligned with the needs of developing countries and that it serves corporate interests in developed countries disproportionately.[23]

Figure IV.13

Concentration indices of market capitalization, revenues, physical and other assets, and employment, top 30 software and IT firms in the UNCTAD Consolidated Financial Statements database, 1995–2015



Source: UNCTAD (2017), box figure 6.B2.1.

Note: Concentration indices here measure the top 30 firms' observed share in the specified variables relative to their hypothetical equal share, assuming equal distribution of the specified variable among firms. An increase in the indices indicates an increase in market concentration.

23 Those authors highlight the fact that pharmaceutical patent protection is extended for global pharmaceutical companies at the expense of the health of the poor.

Moreover, multiple studies indicate that there is no conclusive evidence — especially for countries that lie at a distance from the technological frontier — that greater IPR protection has a strong positive influence on domestic technological development (Odagiri and others, 2010; Dosi, Marengo and Pasquali, 2007).

In fact, aggressive IPR measures may have impeded technology transfer in many developing countries, as they pose significant restrictions on knowledge flow. Indeed, some trade agreements even contain restrictions on so-called investment measures (including prohibitions on imposing technology transfer or domestic content requirements (United Nations, 2011, p. 182)), which limit the scope of international trade with respect to facilitating technology transfer. Such measures could also encroach on countries' policy space for conducting industrial policies, subsequently affecting their innovation efforts. Chapter V discusses how to improve the flexibilities of the global IPR regime.

Yet another development that poses challenges for bridging the technological divide is the rising salience of social and economic networks in technology diffusion and innovation. While theoretical and empirical studies found that knowledge could potentially spread across networks quickly, given the short average social distance between individuals, households and firms (Jackson, Rogers and Zenou, 2017), such a rapid transmission of knowledge does not always occur or translate into broad adoption of new technologies.

One key reason is that firms, households or individuals with similar characteristics — e.g., income and technological capacity levels — behave in clusters. This means that technology information flows and technology externalities would be confined largely within these clusters, which could lead to differences in technology adoption behaviour between groups. It could also slow the spread of technology information across groups and lead to underinvestment in technology owing to complementarities in behaviours. For example, a firm will be less likely to invest in a new technology if its partnering firms are not doing the same.

Furthermore, from a dynamic perspective, social and economic structures are constantly changing and the interaction between technology diffusion and network formation could lead to a second-round effect which would further worsen the technological divide.

Clustering of interactions within networks of firms with similar technological capacity could lead to larger technological divides

A potential risk is that diffusion of new technologies will occur largely within clusters of firms with high technological capacity. This could lead to an even faster improvement in these firms' technological capability, which in turn would make them even more inclined to interact with each other. Meanwhile, firms with low technological capacity would be excluded from participation in this dynamic and could risk losing the opportunity to reach the technological frontier owing to the lack of interactions with frontier firms. Under this scenario, small initial differences in technological capacity could potentially lead to large technological divides in the long run.

Role of Governments in bridging the technological divide

A country's innovation system must be developed in line with its development circumstances and national technology aspirations

Within the context of these continuing and emerging policy challenges, the importance of the role of Governments in bridging the technological divide cannot be overstated.

In principle, a Government needs to develop its NIS in line with its development circumstances and national technology aspirations. The process of advancing the NIS should also be informed by the ambitions of the 2030 Agenda for Sustainable Development and other global and regional initiatives, such as the Paris Agreement adopted under the

United Nations Framework Convention on Climate Change[24] and the Sendai Framework for Disaster Risk Reduction 2015–2030.[25] Policies need to steer the system towards striking appropriate balances, as discussed earlier. Further, policymakers need to be guided by their continuous assessment of ever evolving development and institutional contexts to ensure that the system proceeds in the right direction.

Innovative and absorptive capability gaps need to be narrowed in bridging the technological divide

Specifically, Governments, especially in developing countries, should aim at achieving the following goals in their efforts to bridge the technological divide. First, innovative and absorptive capability gaps need to be narrowed. A key component of this effort would be to improve overall human capital, with targeted support directed towards disadvantaged groups. Policy actions to improve the education system should focus on children's early development, with greater exposure to innovation provided for women and disadvantaged youth (Bell and others, 2017), and on incentivizing workers to invest in skills relevant for the rapidly evolving labour market. To support prospective workers in their efforts to identify the right skills, Governments can work with the private sector and labour unions on developing programmes that provide key information on strategic sectors, including on employment prospects, career pathways and demands for existing and emerging skills.[26]

With a view to improving innovative and absorptive capacities, firms' managerial and organizational capabilities must be continuously improved. Governments can provide support to firms, especially small and medium-sized firms, by facilitating the provision of business advisory and management extension services. This is particularly important, as firms often lack the scale required to assess the value of these services (Cirera and Maloney, 2017) or are unaware of what they themselves lack in terms of managerial and organizational capabilities (Bloom and Van Reenan, 2007). In providing support, Governments could focus on introducing credible mechanisms which would ensure that employees who are in the best position to assess a new technology are sufficiently incentivized to accurately report their assessment (for example, offers of wage contracts conditional on process efficiency) (Atkin and others, 2017).

Technology information must be made widely accessible in supporting innovation and technology diffusion

Second, technology information must be made widely accessible. In supporting innovation, Governments need to play an active role in facilitating transfer of technology information within the NIS. As discussed earlier, the successful experiences of some East Asian economies in the early phases of their technological development highlight the potential of establishing a network of institutions for technology diffusion, which could include public sector laboratories, developmental consortia and large public firms. These institutions would identify available knowledge and other resources useful for technological diffusion and make these resources available to other actors within the NIS.

In supporting technology diffusion, Governments need to actively foster public awareness of new technologies, including through demonstration programmes and a reduction in the costs associated with the search for technology information. Governments should also acquire a better understanding of the structure of existing social and economic networks, which are key information-sharing channels. Governments can develop plans for communicating technology information, including, for example, through identification

24 See Adoption of the Paris Agreement in United Nations Framework Convention on Climate Change (2015).

25 General Assembly resolution 69/283, annex II.

26 Singapore has inaugurated such a practice through its Skills Framework initiative (see www.skillsfuture.sg/skills-framework).

of "champions" of new technologies which are well connected within a given network structure.

Policymakers need to improve financial access and make it more inclusive

Third, financial access needs to be improved and made more inclusive. Governments can work with a range of stakeholders, including academia, the private sector and consumer advocacy groups, in selecting and providing funding for products that have great welfare-enhancing potential but are yet to be commercialized. In particular, Governments might consider setting up innovation funds with a diversified portfolio (United Nations, 2017c). These funds could spread risks across multiple investments, so that gains from successful investment would compensate for losses arising from failures. Governments can also provide tax incentives which encourage innovation, including R&D tax incentives for small and new firms and refundable tax credits that would be applicable when firms have negative tax liabilities (IMF, 2016).

Policymakers also need to ensure the presence of a vibrant venture capital (VC) industry, in view of its vital role in connecting institutional investors with high-potential innovation projects at the early stages of their development cycles. The United Nations Economic Commission for Europe (2009) argues that Governments need to support all four stages of the VC cycle: fundraising, investing, value-adding and exiting. Potential support can range from helping institutional investors better understand venture capital as an institutional investment class to introducing government fund-of-funds programmes which support VC funds during the natural down cycles of fundraising; and from investing in VC funds with conditions that incentivize VC managers to contribute to the success of their investments to creating an environment in which VC investors can sell their ownership stakes at prices that compensate them sufficiently for the risks they take.

Enabling institutional arrangements and complementary infrastructures need to be put in place to support innovation and technology diffusion

Fourth, institutional arrangements and complementary infrastructures which enable both innovation and diffusion need to be put in place. Governments need to address systemic failures—which include market failures, such as unfair market competition, markets' inability to price in positive externality, and asymmetric information—and inadequate or inefficient interactions between NIS actors (United Nations, 2011, p. 132).

A proper IPR regime must be established and maintained to ensure that firms are sufficiently incentivized to innovate, without unnecessarily deterring technology diffusion.[27] Governments also need to play an active role in technology standard-setting efforts, as introduction of standards can help to kick-start penetration of new technologies. A more detailed policy discussion on these institutional issues, including their international dimension, is presented in chapter V.

Technology policy could benefit from the insights generated by the behavioural economics literature

Formulation of these policy actions could benefit from the insights generated by the behavioural economics literature, which emphasizes that economic agents sometimes act in ways that deviate from the rationality assumed under many of the economics models that have informed policymaking processes for decades.

Policymakers must engage in deliberations and make decisions regarding the pace of technology innovation and diffusion, in order to minimize disruptions to social and political stability. At the same time, Governments should remain aware of their own limitations and take a flexible approach towards formulating and implementing policies.

Last but not least, while national policy actions are central to the narrowing of the technological divide, those efforts cannot be fully effective without strong international

27 For example, technical information contained in patent documents need to be made publicly accessible so that innovations can have positive spillover effects on the broader technology community.

collaboration. Accordingly, there should be policy options for closing technology gaps between and within countries, which will be discussed from an international cooperation perspective in chapter V.