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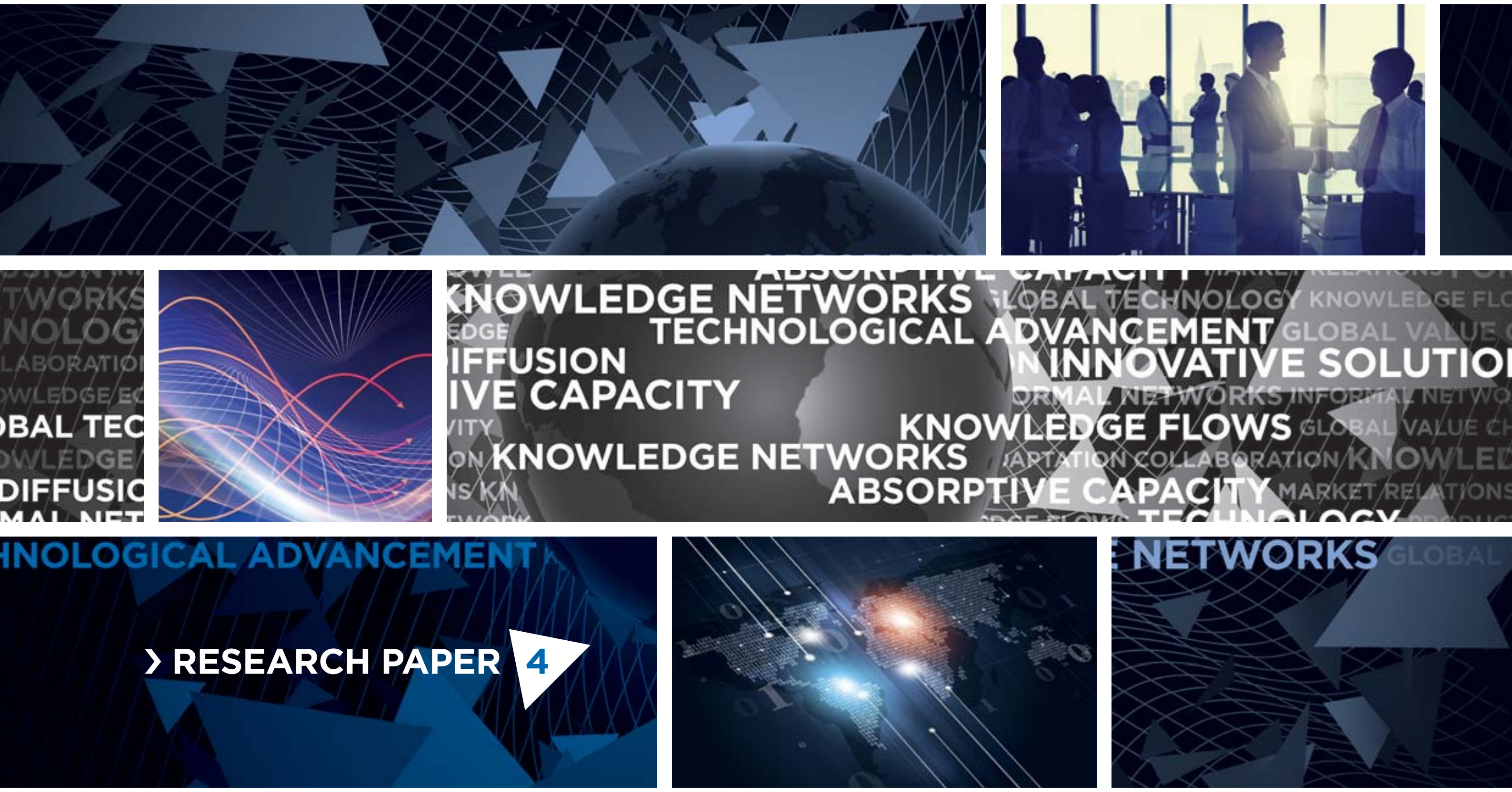
THE DYNAMICS OF GLOBAL TECHNOLOGY AND KNOWLEDGE FLOWS



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Knowledge transfer
Shift

The Dynamics of Global Technology and Knowledge Flows

This paper is intended to provide policymakers with an overview of how technology and knowledge flow at the regional and global levels. After presenting the economic role of knowledge as well as a number of basic concepts related to its dissemination, this paper identifies certain pre-requisites for successful knowledge transfer. It subsequently discusses various channels for transfer and diffusion, including integration by firms in global value chains, participation by public and private actors in knowledge networks, and the movement of skilled individuals among institutions and across geographic regions.[1] Throughout, the paper highlights the gradual nature of knowledge diffusion, as well as the role of collaboration in the generation, dissemination, and adaptation of innovative solutions. Finally, the paper identifies the types of policy environments that may best attract and accelerate knowledge flows, suggesting certain actions that policymakers can take to improve their region's innovative capacity.

1 Throughout this paper, the term "region" is used in a generic sense. Thus it may refer to a country, a group of countries, or a part of a country.

Introduction

Increasingly, it is the capacity to create and to commercialize new ideas, rather than endowments in natural resources, which explains productivity and growth differentials across regions. Technological advancement can provide new and more cost-effective solutions to challenges in critical areas such as education, food and water, health, and shelter. It has had a profound impact on the industrialization of developed countries. The diffusion of technology and knowledge enables "catch-up", that is, the closing of the technology gap between actors within and across countries.

Setting the Stage: How do Technology and Knowledge Flow?

Knowledge economy

Covering various time periods, recent studies show a positive relationship between business investment in knowledge-based capital, on the one hand, and macroeconomic growth and productivity change, on the other. For instance, based on estimates for the period 1995-2007, investments in this type of capital account for some 34% and 20% of labour productivity growth in the United States and in 14 countries of the European Union, respectively (Corrado *et al.* 2012; OECD 2013). What is more, knowledge is a significant driver of development: the correlation between the accumulation of knowledge, as measured by the Knowledge Economy Index, and levels of economic development amounts to some 87% (World Bank 2008). In addition, professionals producing or manipulating knowledge, such as scientists, engineers, programmers, and intellectual property (IP) lawyers, represent an ever-rising and highly skilled part of the workforce (WIPO *et al.* 2014).

Two main factors contribute to the spectacular rise of the "knowledge economy" (David & Foray 2003). First and foremost, innovation is becoming the essential means for businesses and other organizations to compete in a globalized world. At the same time, the advances in information and communication technologies (ICTs) have revolutionized the modes of knowledge-based production. In particular, ICTs allow people to remotely access and process information, to exploit enormous databases, as well as to intensify the creative interaction not only between researchers but also among product designers, suppliers, and end consumers.[2]

Knowledge transfer and diffusion

Technology transfer is the movement of knowledge or technology between two specific entities, for instance, from one business to another (Roessner 2000; Wahab *et al.* 2012). A technology transfer transaction, which involves a source and a recipient, should result in the sustainable deployment of a solution and improvements in the recipient's knowledge base. Technology diffusion is a broader concept that encompasses the social change to which the transfer of technology may give rise over time.

2 Economic scholarship has taken account of this development. After Solow (1957) showed the limits of neoclassical theory, which explained economic performance in terms of capital and labour, new growth models emphasize the importance of knowledge in increasing productivity (Romer 1986; Lucas 1988). According to their proponents, investments in knowledge and human capital endogenously generate growth through the transfer of knowledge between different industries or firms (Romer 1986).

While information simply represents a flow of messages, knowledge is created and organized by the flow of information and also through a dynamic social process of mutual exchange and shared learning (Blackler 1995; Howells 2002; Howells 2012). The spread and use of knowledge – like the spread and adoption of new technology solutions – does not take place instantaneously (David 1990). Rather this is an evolutionary process and the impacts of the dissemination of technologies and knowledge, such as improvements in productivity, can take a while to become measurable.

Knowledge can either be "codified" or "tacit" (Polanyi 1966). The type of knowledge influences the ways in which it can be transferred and absorbed. Codified (also called "explicit") knowledge is knowledge that can be effectively expressed through symbolic forms of representation such as written or spoken words. An example is the description of an invention in a patent application. The transmission of codified knowledge does not require the recipient to directly "experience" the know-how in question, thus allowing for the use of such formats as blueprints or operating manuals (Howells 2002; Howells 2012).

In contrast, tacit knowledge is challenging to articulate or codify, as it consists of experience and understanding accumulated by a person or organization over time. Tacit knowledge (also referred to as "know-how") is an essential and critical element of all knowledge. Even explicit knowledge cannot be understood in isolation and requires some element of tacit knowledge for its interpretation (Polanyi 1966). The holder of tacit knowledge may be unaware of, or unable to describe, all the background knowledge that is essential for the successful deployment of an invention, or for the execution of a specific skill. Symbolic forms of communication may prove inadequate to accurately capture and convey tacit knowledge (Gertler 2003). It is "an art which cannot be specified in detail and cannot be transmitted by prescription, since no prescription for it exists" (Polanyi 1962). As a result, tacit knowledge is considered particularly "sticky", or difficult to transmit. Its transfer generally requires sustained, face-to-face interactions.

Absorptive capacity

"Absorptive capacity" provides a critical foundation for sharing technology and knowledge. Defined as the ability of a firm or region to integrate and use new knowledge to generate innovation, absorptive capacity is an essential prerequisite to successful knowledge transfer at the individual, firm, or regional level (Cohen & Levinthal 1990). The reason is simple: a minimum knowledge base and capabilities are required for the transfer of both explicit and tacit knowledge (Ernst & Kim 2002; Abreu 2011; Caragliu & Nijkamp 2011). The precise foundation required for successful technology and knowledge transfer depends on the field of technology and also on the solution being shared. A firm or region may develop absorptive capacity that is restricted to a niche area.

A firm or region's level of absorptive capacity depends in large part on the quality and preparation of the workforce, the result of public and private investments in education and training, as well as experience and research and development (R&D) investments. Other influential factors include physical capital, organizational processes, and social and cultural factors (Fu & Polzin 2010; Brem & Moitra 2012). The more developed the knowledge base of the recipient, the higher the chance for effective knowledge transfer and absorption. The difference in technological capacity between partners also determines the effectiveness of knowledge transfer, with a greater technology gap potentially slowing knowledge flows.

Absorptive capacity develops gradually, as individual transactions contribute over time to building the knowledge base of a firm or region. Accumulated knowledge and experience, gained through engagement with innovators and also through learning by doing, can create positive spillovers and provide a source of endogenous growth. This can complement exogenous growth derived from collaboration and knowledge exchange with external parties such as multinational firms (Arrow 1962). In other words, firms and regions can leverage innovation and engagement with external actors, even as they draw on their own growing knowledge base for competitive advantage (Runiewicz-Warden 2013).

The role of firms

An important repository for knowledge, the private sector plays a key role in regional and global knowledge transfer. Globally, the part of total gross expenditure of R&D that is financed by business enterprises amounts to some 35% on average (WIPO *et al.* 2013). Such investments combined with long-term experience give rise to a significant body of explicit and tacit knowledge.

Firms need to actively develop or acquire superior solutions in order to retain their competitive edge in the marketplace (Dahlman 2010). They must also enhance efficiency, which for multinational corporations (MNCs) often means distributing their R&D and production activities globally. Entering new markets, global firms collaborate with local partners to obtain market knowledge and to adapt their offerings to enhance their chances for commercial success (Parthasarathy *et al.* 2014). Globally distributed R&D and production, as well as a recently intensified focus on customers in emerging markets are creating new channels for knowledge and technology flows.

In response to factors such as rising product complexity and to manage cost and risk, firms rely increasingly on open, collaborative innovation models to develop, adapt, and commercialize new offerings (Chesbrough 2003; Pénin *et al.* 2011). Instead of developing and commercializing processes exclusively within the boundaries of a single corporation, companies are working with external actors in order to enhance the innovative process. They therefore need to simultaneously disclose and protect their know-how (Brant & Lohse 2014a).

Open innovation approaches involve a growing range of public and private actors, including firms, research institutes, universities, spin-offs, NGOs and foundations, individuals, and public-private partnerships (Gross 2013). With ICT advancements and the globalization of production networks, partners can now be located anywhere in the world. Open innovation is creating tremendous opportunities for knowledge and technology generation and transfer, whether at the regional level through clustering, or at the global level through integration of firms in international production and knowledge networks (Ernst & Kim 2012). It also enables new actors and regions to integrate into global networks.

Supplier relationships provide a key channel for sharing knowledge, thereby also improving the recipient's absorptive capacity. They facilitate knowledge flows because the firm outsourcing an input has an incentive to transfer the technology needed for its efficient production. In fact, that firm will eventually be the consumer of the input and must ensure compatibility with its own production process (Baldwin & Lopez-Gonzalez 2013). For instance, to enable local suppliers to meet high standards for quality, cost, efficiency, and safety, MNCs will often work with them to upgrade their capabilities, sharing technical knowledge and providing financing, hardware, software, and other resources (Ernst & Kim 2002; Sonmez 2013). Over time, the relationship may evolve to include joint design and other collaborative, innovative work (Sonmez 2013). An analysis of the automobile sector in Turkey found that collaboration between MNCs and local suppliers over many years led to knowledge transfer in relation to R&D and management structures, as well as production and production processes. Such collaboration also enhanced the skills of local engineers, contributing to the accumulation of know-how and upgrading the knowledge base of the local economy (Sonmez 2013).

Because sustained collaboration builds trust among partners, and repeated interactions foster the exchange of tacit knowledge in particular, partnership can be a crucial channel for knowledge and technology diffusion (Box 1) (Doepfer 2012). How this works in practice is described in more detail later in this paper. Appropriate government actions can create an enabling environment for knowledge transfer through a range of different forms, including collaborative innovation (Brant & Lohse 2014a).

BOX 1: GE-Transnet Joint Venture: Learning by Doing within a Partnership

General Electric and Transnet Freight Rail have been engaged in a manufacturing joint venture (JV) in South Africa for several years. As part of this partnership, more than 150 advanced green locomotives have been built for customers in South Africa and other African markets, resulting in the emergence of a centre of excellence for locomotive technology near Pretoria. Transnet Freight Rail is part of Transnet SOC Ltd., South Africa's state-owned ports and rail operator.

The collaboration began in 2010 as an order to purchase "Evolution Series" advanced locomotives from GE. Transnet's role was to assemble the majority of the locomotives – which use advanced materials and innovative computer-controlled operating architecture – in South Africa, using parts made in the United States. GE initially set a self-imposed local content of 30% for the locomotives. In 2012, the South African government announced that this target had been exceeded, and that the locomotives made included 37% local content, thus enhancing regional economic benefits and knowledge spillovers. Working with GE, in a relatively short time domestic suppliers were able to increase their supply of certain inputs, at the required level of quality, for the production of the locomotives.

Deployment of the advanced locomotives made by GE and Transnet will result in significant benefits for Transnet, as well as other railway operators in Africa: lower fuel and maintenance costs, significantly lower emissions, and improvements in hauling capacity. As infrastructure is a critical foundation for development, the positive economic impacts of the manufacturing JV are expected to be significant. Moreover, through collaboration, knowledge and technology are being shared between GE and Transnet, contributing to higher productivity, creation of skilled jobs in the region, and a stronger industrial base for South Africa.

Transnet is now encouraging GE and other infrastructure companies to set up permanent train-assembly plants, replicating an earlier initiative by the South African government to attract partners from the automotive industry, which established manufacturing plants in the country, resulting in jobs and export capacity in that sector.

Sources: SAnews 2012; Bhuckory & Burkhardt (2014); GE 2014

Channels for Technology and Knowledge Diffusion

The four main channels for knowledge transmission are market relations, formal networks, spillovers, and informal networks (Figure 1) (Trippl *et al.* 2009). For businesses, the choice between the different channels largely depends on the transaction costs. Product standardization may increase reliance on arm's length market transactions. In contrast, customization of products and processes, which involves transaction-specific investments and requires greater coordination, tends to increase transaction costs. In this case, firms may prefer to retain certain activities within a limited network or in-house, potentially reducing knowledge transfer to partners. However, it should be noted that the four different modes of knowledge transfer are interrelated and often complementary.

	Knowledge transfer	Collective learning
Formal engagement	**Market relations** ▪ FDI and international trade in goods and services ▪ Purchase/import of goods ▪ Licensing of IPRs	**Formal networks** ▪ R&D collaborations ▪ Global commodity chains, global value chains, global innovation networks
Informal engagement	**Spillovers** ▪ Patenting activity ▪ Labour mobility ▪ R&D at universities ▪ Scientific publications	**Informal networks** ▪ Interpersonal contacts and networks

Figure 1: Channels and mechanisms for knowledge transfer and diffusion
Source: adapted from Trippl et al. (2009)

Market relations

Market relations refer to the transfer of technology and knowledge that is "embodied" in a product or service. This type of knowledge transfer encompasses international trade in goods and services, foreign direct investment (FDI), and channels such as formal consulting, contract research, licensing of technology, and the acquisition of intellectual property rights (IPRs) (Trippl *et al.* 2009). Market relations give rise to two basic knowledge transfer mechanisms, both of which centre on explicit knowledge (Keller 2001; Shih & Chang 2009):

- *Direct learning* about foreign technological knowledge, through access to blueprints or designs of new products and processes. Such knowledge may be proprietary (*i.e.* protected by IPRs) and may thus need to be licensed from its owners. Licensing of IPRs, discussed later in this paper, is an important channel for knowledge transfer. It can provide the right to use a technology solution, as well as access to associated explicit and tacit knowledge.
- *Indirect access* to international technological knowledge, through working with intermediate and final products that become available due to international trade and FDI. In other words, some knowledge transfer occurs through the mere access to such goods, which may allow for reverse engineering.

It is noteworthy that FDI and openness to international trade do not automatically imply knowledge diffusion. As mentioned, knowledge diffusion requires the recipient to possess adequate absorptive capacity (Lane *et al.* 2006; Lichtenthaler & Lichtenthaler 2009). In addition, unless the domestic recipient is able to benefit from foreign tacit technological knowledge, FDI may result only in "passive technological spillover" (Keller 2001). In other words, even if reverse engineering is carried out, without technological partnering, the recipient would not benefit from the tacit knowledge held by the inventor of the solution.

Formal networks

Formal knowledge networks include different forms of global supply and value chains, formal collaborations such as joint R&D, and innovation networks. Formal networks have a contractual basis underpinning participation by different actors. In comparison to market relations, formal knowledge networks offer greater possibilities of knowledge creation and diffusion, as networks generally involve closer collaboration and more collective learning (Trippl *et al.* 2009).

Global supply chains (GSCs) are transnational production networks established by MNCs to take advantage of the global trade regime. The segmentation of production in GSCs creates various roles, from primary commodity exports, to export-processing assembly, to component supply subcontracting, to original equipment manufacture and, eventually, original brand manufacture. These roles progressively demand more organizational and entrepreneurial capabilities. A recent study has shown that knowledge transfer increases with the intensity of supply chain linkages between countries (Piermartini & Rubínová 2014).

Global value chains (GVCs) focus on the value accrued by firms in the chain and involve a range of production and service activities in addition to manufacturing within international networks (Parrilli *et al.* 2013). The case of the iPad, manufactured by Apple, helps to illustrate the dynamics within GVCs. While Apple designs the iPads, the product is given material reality by a GVC stretching to Asia for manufacturing and assembly. Apple receives some 30% of the retail price as profit. This indicates the firm's dominance of the GVC, in which it controls the design to which suppliers have to conform (The Economist 2012).

Other types of formal networks, for instance R&D collaboration, can foster knowledge exchange. According to one study, firms in the Vienna software industry engage in a range of R&D collaborations in relation to development, applied research, prototyping, and testing, with the objectives of delivering innovations that are new for the market and entry into new technical fields (Trippl *et al.* 2009). In terms of partners for collaborative R&D, Vienna software firms ranked commercial R&D firms, customers, competitors, technical colleges, and universities as the most important.

In many parts of the world, engagement between firms and universities is a key factor driving innovation and the generation of new knowledge, as well as its application in the marketplace. As in Vienna, linkages in Silicon Valley with universities such as Stanford University and the University of California, Berkeley, were critical to developing the innovative capabilities of local technology firms (Saxenian 1994). Legal frameworks that enable universities and research centres to protect and manage the outcomes of their research activities can provide a foundation for such linkages (Box 2).

BOX 2: Commercializing Publicly Funded R&D in the United States: The Bayh-Dole Act

Interest in the United States (US) in technological innovation, and in promoting the application of new knowledge generated through publicly-funded research, led to amendments to the Patent and Trademark Act in 1980. The *Bayh-Dole Patent and Trademark Amendments Act of 1980*, which became known as the Bayh-Dole Act, allowed private actors to seek patents on results derived from federally funded research. It also allowed them to license such patents to other private parties. The legislation was aimed at incentivizing the application and commercialization of federally funded R&D and facilitating private sector development, by loosening restrictions on patent ownership for federally funded research outcomes. It also aimed to encourage cooperation among academia, small businesses, and established industry players for the development of new products and processes for the marketplace.

The rationale for this Act was that, prior to 1980, only 5% of government owned patents were ever used in the private sector despite their commercial potential. This was because the government controlled the title to any inventions associated with research performed with government support, whether it had been conducted at federal laboratories, in universities, or by individual companies. The result was a lack of incentive for the private sector to invest additional resources in further developing or commercializing publicly funded R&D outcomes. Studies have shown that the Bayh-Dole Act stimulated new technology transfer activities at many US universities that receive federal funding, following expansion of their commercial and marketing efforts.

Since the introduction of the law in 1980, more than 8,778 new firms have been established in the US to commercialize academic R&D, with as many as 3,927 start-ups still functional as of FY2011. Moreover, the number of patents awarded to universities also increased from 390 to 3,088 between 1980 and 2009. Although federal government still remains the dominant source of funds, the university-industry collaboration also resulted in increased corporate financing for academic R&D, reaching 5.8% of the total in FY2009.

Sources: Mowery et al. 2001; Schacht 2012

Spillovers and informal networks

The quasi-public nature of knowledge means that, to some degree, positive externalities are generated by virtually any private investment in new technology. The benefits of an expanding knowledge base that accrue to firms and individuals, including third parties who do not directly invent and innovate, are referred to as "knowledge spillovers" (Keller 2001). A series of studies have examined the dynamics of knowledge spillovers, looking at patent activity and citations, labour mobility, interpersonal interactions, university R&D levels and innovation rates (Jaffe 1993; Howells 2002), as well as entrepreneurship (Acs 2010; Braunerhjelm *et al.* 2010; Acs *et al.* 2013).

Spillovers derived from access to patent information or R&D outcomes of universities represent access to knowledge, but they do not automatically translate into dynamic processes of collective learning and follow-on innovation. Much technological knowledge is tacit, and the transfer of know-how requires sustained face-to-face interactions such as demonstrations, personal instruction, and the provision of expert services like advice and consultation (David 1993; Audretsch & Feldman 1996). Informal channels, such as interpersonal contacts and the mobility of skilled labour, are thus critically important to supporting sustained knowledge diffusion and absorption – and improvements in the knowledge base.

Skilled workers with explicit as well as tacit knowledge act as individual agents assisting in the production and transfer of knowledge (Lundvall & Johnson 1994; Minbaeva & Michailova 2004). The international flow of people is an important cause and consequence of the globalization process (Leamer & Storper 2001; Levin & Barnard 2013). Communities of interaction, like movement of skilled labour, are an important contributor to the spread of knowledge. Examples include scientific publications and the movement of star scientists within and across organizations and regions (Nonaka 1994; Perkmann *et al.* 2013).

The transfer of tacit knowledge requires shared understanding, thus highlighting the contribution of organizational and relational proximity to knowledge transfer (Gertler 2003). "Organizational proximity" refers to intra-firm structures in which people and knowledge move. "Relational proximity" designates a broader set of intra- and inter-firm networks (Boschma 2005; Tamásy *et al.* 2008). Organizational and relational proximity, which facilitate the movement of skilled workers, are considered binding forces for knowledge transfer (Tamásy *et al.* 2008). Even as they move transnationally, technological entrepreneurs and workers tend to draw on linkages with organizations and institutions of their home country, and to maintain alliances with previous work organizations and former colleagues abroad (Saxenian 1994). Expatriation programs have been found to be among the most effective drivers of international interpersonal knowledge transfer (Glückler 2008).

Trust plays a central role in the generation and diffusion of knowledge through interpersonal relations (Levin & Cross 2004). Trust is central in particular to the transfer of tacit knowledge, which is associated with the recipient's perceptions of the source – and with the source's conviction that he can trust the recipient to not misappropriate the information imparted. Generally trust evolves over time through repeated interactions.

Geographic proximity and regional innovation systems

Technology diffusion and physical space mutually influence each other. In particular, since tacit knowledge transmission relies heavily on face-to-face interactions, it is perhaps not surprising that flows of know-how are particularly circumscribed by place. The relatively high expense that individuals must incur to change physical location suggests that, the higher the relative importance of tacit knowledge in a given field of technology, the more knowledge creation and diffusion are likely to be geographically concentrated (Audretsch 1998; Keller 2001). However, especially given the considerable advances in ICTs in recent years, the impact of geographical proximity on knowledge flows is neither straightforward nor direct.

A regional innovation system (RIS) includes all elements that interact and determine the innovative capacity of a region. It encompasses the infrastructure and activities that enhance the ability of individual actors (firms, research institutes, and others) in a geographic location to absorb, create, and diffuse knowledge, and to transform it into new, economically meaningful solutions. The economic, political, and institutional relationships within a region can generate knowledge flows and a "collective learning process", thus increasing absorptive and innovative capacity over time (Wolfe 2000; Ashheim *et al.* 2012). University-firm linkages, transactions among firms, and public services such as government R&D subsidies are all components of an RIS.

RIS are distinct across regions by virtue of being embedded in the local social, cultural, economic, and political contexts, and each has its own innovation pathways and processes (Runiewicz-Warden 2013). An RIS may encompass multiple sectors, and it may be made up of several individual clusters.

Clusters are "geographic concentrations of interconnected businesses, suppliers, service providers, coordinating intermediaries and associated institutions like universities" (Muro & Katz 2011). They tend to have a more narrow focus than RIS, which they complement and with which they share many characteristics. Clusters typically centre on one sector or field of technology and they tend to evolve in industries in which tacit knowledge is particularly important (Audretsch 1998; Qian *et al.* 2012). They may emerge as "agglomeration" forces draw actors engaged in similar activities towards a geographic region, leading to the formation of clusters such as the artisanal cheese cluster in Vermont in the United States (Muro & Katz 2011). The development of a cluster may confer a competitive advantage to a region, the result of concentration of niche skills and knowledge.

Networking among public and private sector actors within a cluster or RIS can enable participants to access complementary know-how, resources, and skills. In addition to pushing the technological frontier outward, networking and collaboration can enable firms to more effectively confront challenges in the marketplace and to address risk (Runiewicz-Warden 2013).

Cross-fertilization among different industry clusters can be particularly valuable in light of growing product complexity and the cross-disciplinary nature of innovation today. Innovation often derives from combining existing knowledge. This is especially true in traditional industries, for which innovation often comes from outside. Thus such industries stand to gain from interactions with other industries, especially high tech industries, within an RIS (Autant-Bernard *et al.* 2013). Cross-industry interactions can give rise to new centres of excellence (Box 3), further enhancing the innovative capacity and competitiveness of a region.

BOX 3: Knowledge Spillovers: Wichita Aircraft and Med Tech Clusters

The city of Wichita, in the United States, is home to an aircraft cluster that brings together skilled workers, research institutes, suppliers, and manufacturers. The cluster, which counts over 40,000 workers, has generated new technologies with great potential for the aviation as well as other sectors. One example is composite material, which is a resin-bound carbon fibre-reinforced material with application in aviation and beyond.

Starting with the first flight by the Wright Brothers, this cluster developed steadily over the past hundred years. It has been credited with spawning the creation of many start-ups, forcing local firms to become more competitive, and creating global market opportunities for participants. Technological advancement in the aviation industry, along with growth of the cluster over time, has created a steady demand for new technical skills and knowledge, drawing in specialists and engineers from other regions and sectors and inducing local experts to innovate to solve new challenges. Relationships among personnel and their movement between companies, most of which were locally owned and controlled until the 1980s and 1990s, enhanced knowledge spillovers.

Wichita State University, a public research institution, is a central actor in the cluster, training specialists essential to the continued success of the cluster, and, through its R&D activities and collaborations, generating innovative solutions for firms. In 1990, local firms and federal, state, and local governments together established the National Institute for Aviation Research at Wichita State University. The NIAR supports the US aviation industry by providing training, research, and technology transfer.

One innovation to emerge from the cluster was composite material. More resilient and lightweight than aluminium, it is gradually replacing aluminium in aircraft. NIAR has played a key role in the development of this new material, which is ideal for use in aircraft.

Now, with encouragement from federal and regional governments, and engagement with universities, efforts are underway to foster the creation of new clusters in the region, based on the application of composite material to sectors such as medical devices. This effort leverages knowledge gained about carbon fibre composite material in the aviation industry. New public-private entities have been established, such as the National Center of Innovation for Biomaterials in Orthopaedic Research, to research and develop new solutions using composite material in the medical and bioscience fields.

Source: Pett & Wolff 2011

The economic value in “bringing together different but complementary pieces of knowledge” has been identified in the literature, providing conceptual clarification about the role of regional specialization and regional diversity in developing and sustaining regional advantage (Asheim *et al*. 2011). One study, highlighting the importance of "related variety", suggests that regional specialization involving sectors that are both technologically related and complementary is most likely to induce interactive learning and regional innovation (Asheim *et al*. 2011). Some degree of complementarity, or "cognitive proximity", may be required to enable effective communication and interactive leaning among different sectors in a region (Nooteboom 2000), since knowledge will spill over from one sector to another only if the sectors are somehow complementary (Asheim *et al.* 2011).

Mobility of skilled workers in local industrial clusters with highly specialized labour markets provides opportunities to transfer tacit knowledge between economic actors in the same region. However, it is the combination of localized learning and access to *distant* networks of expertise and knowledge that helps to sustain regional dynamics (Bathelt *et al.* 2004). Global linkages provide flows of knowledge, people, and capital exogenous to the local industrial clusters (Parrilli *et al.* 2013). Global networks include various channels – formal and informal, market and non-market – that enable the circulation of new knowledge across the network. A combination of global and local forces shape innovation capabilities and competitiveness, helping some regions grow and prosper, and making their trajectories of technical advancement difficult to imitate (Box 4).

BOX 4: The Technological Trajectory of Bangalore (Bengaluru): Local and Global Factors

The revenues of the Indian ICT services industry grew from US$81 million in 1985-86 to US$44.1 billion in 2008-09. More than three-quarters of this growth came from exports, making India the world's largest exporter of ICT services. About one-third of these exports came from Karnataka state, mostly from firms located in and around Bangalore, the state capital. The technological trajectory of the ICT services industry in Bangalore over the past quarter century has been influenced by the interplay between the organizational structure of industry in the region, the institutional setting shaped by the changing policy regime, and the relationships between local actors and global customers and markets. The growth of the industry in Bangalore has been accompanied by significant qualitative shifts, thanks to the upgrading of technical and managerial skills.

Until the 1990s, ICT service exports were little more than "body-shopping", or the provision of low-cost, low value-added services at customer service sites across the world. In the 1990s, the establishment of Software Technology Parks (STPs), which provided critical data communications infrastructure, and exempted export earnings from tax, coincided with the creation of a liberal economic environment in the country, as India adopted policies favouring more open trade and FDI. The combination of policy initiatives, combined with steady growth in global demand, especially following the commercialization of the Internet in 1993, set the stage for new forms of engagement between the Indian ICT services industry and global markets. As the first STP was established in Bangalore in 1990, it reinforced the skill advantages that the region already possessed and made it the leading choice for domestic firms and foreign MNCs establishing themselves in India.

The new form of engagement that resulted was marked by the emergence of a "Global Offshore Delivery Model" in which offshore development centres (ODCs) were established in India, particularly in Bangalore. This provided opportunities for local workers to perform a broader range of tasks involving higher value-added services for foreign customers. It also offered long-term engagement and exchange with foreign counterparts, which enhanced the technical and managerial skills of Indian employees.

Since the turn of the millennium, the industry in Bangalore has been characterized by greater innovation. This has been driven in part by a deeper labour market, influenced by factors including the return of expatriate engineers from places like Silicon Valley. By 2009, software products and engineering services accounted for a fifth of exports, signalling a qualitative shift in the industry from being a mere provider of low-cost ICT services to a source of innovation. In the area of embedded systems, for instance, firms from Bangalore provide innovative services in a range of specialized engineering domains such as automobiles and telecommunications.

Source: Parthasarathy (2010)

Today's Multi-directional Knowledge Flows and Global Innovation Networks

It used to be that FDI, technology, and knowledge flowed primarily between developed countries. However, FDI inflows to developing countries have risen dramatically since the 1990s, reaching a new high of US$778 billion, or 54% of the total, in 2013 (UNCTAD 2014). In addition, FDI movement is no longer restricted to flows from developed to developing regions. Flows between developing countries ("South-South"), as well as from developing to developed regions ("South-North"), have also been growing. In 2013, developing and transition economies together contributed to US$553 billion, or 39%, of global FDI outflows, compared with only 12% at the beginning of the 2000s (UNCTAD 2014).

MNCs from developing countries have emerged as key sources of South-South FDI, particularly in low-income countries, though their contribution to global R&D is smaller than that of MNCs from mature markets (Fredriksson 2012). South-South FDI has been described as "organic", characterized for instance by the establishment of a local factory or branch office, whereas "South-North" FDI tends to be "acquisitive", involving firms buying one another (The Economist 2011).

While much advanced technology still comes from developed countries, today there are significant South-South and South-North flows, and developing countries are the source of increasingly valuable innovation. This shift in the direction of knowledge flows is particularly evident in countries such as Brazil, China, India, Mexico, and Russia; these countries are host to significant R&D activities, whether as the site of R&D departments of foreign MNCs and/or as part of the activities of domestic MNCs. As a result, new approaches to studying global technology and knowledge flows go beyond GVCs to consider global innovation networks (GINs).

A GIN is "the establishment within a multinational enterprise of one or more R&D affiliate facilities at different locations around the world" (Maskus & Saggi 2013). The rise of GINs reflects the global dispersion of specific, high value-added activities related to engineering, product development, and research activities (Parrilli *et al.* 2013). It also highlights the emergence of a global division of labour that is facilitating multiple-direction flows of knowledge and the global distribution of high value-added activities including R&D.

These shifts reflect what has already been discussed in this paper, namely, that the transfer and diffusion of technology depend on the transfer of explicit tools and information, as well as of tacit knowledge, and also on the adaptation of exogenous knowledge to suit local needs. Participation in GINs enables firms from developing regions to engage in high value-added activities, to access specialized and advanced knowledge created at the technological frontier, and to upgrade their skills and absorptive capacity.

Increasingly, innovations generated for emerging markets find success in mature markets, where customers, like their counterparts in the developing world, prioritize cost-effective performance. Successful product development for markets with demanding conditions, including limited purchasing power, low levels of literacy, and dilapidated physical infrastructure, can provide a basis for "glocalizing" similar products in affluent markets (Govindarajan & Trimble 2012). This offers an opportunity for MNCs, especially those from developed countries, to draw on a range of ideas and opportunities. One example is General Electric's Mac 400, a portable, lightweight, and easy-to-repair electrocardiogram machine developed for the Indian market. Robust and cost-effective, the Mac 400 proved popular also in mature markets: by 2010, GE had sold 7500 units, of which only 2000 in India (Parthasarathy 2014).

The emergence of GINs, and the expansion of innovative capacity in developing regions, has been helped by a surge in returnees who have worked in developed countries, bringing with them the technical and managerial expertise and experience to conduct research (Parrilli *et al.* 2013). In her work on the "new argonauts", Saxenian (2006) describes the role of entrepreneurs in Silicon Valley – particularly those from Israel, Taiwan, China, and India, who have assimilated into local technical communities since the 1970s – as key agents of change in their respective home countries. They shuttle between Silicon Valley and their home countries, where they play an important role in technological transformation and innovation. They leverage their technical expertise and intimate understanding of the Valley's open networks and decentralized experimentation, tap into their formal and informal networks, and target new markets characterized by unfamiliar technological and commercial challenges.

Intellectual Property Rights and Knowledge Exchange

IPRs such as patents and trade secrets facilitate the packaging and sharing of knowledge and thus contribute to its diffusion, particularly in the context of open collaboration (Bogers *et al.* 2011). IPRs[3] are tools that enable innovators to disclose and share their knowledge without losing control over it, which could cause them to lose their competitive advantage. The precise influence of IPRs on technology and knowledge creation and dissemination varies depending on factors including the market, field of technology, and recipient's level of absorptive capacity. IPRs are only valuable to the extent they can be enforced in relevant jurisdictions.

3 While intellectual property rights other than patents and trade secrets, notably copyrights, are key contributors to knowledge exchange and diffusion, this analysis focuses on patents and trade secrets.

IPRs perform several functions within innovation systems as they:

- Enable innovators to share information they would otherwise keep secret, through patent disclosures and engagement with partners;
- Support the licensing of technology and associated know-how;
- Facilitate the commercialization of solutions developed by entities that lack the resources and experience to refine and scale them, for instance small and medium enterprises (SMEs) and universities;
- Provide leverage that can be used by SMEs to secure investments and complementary resources; and
- Encourage investments in risky R&D ventures, by enabling an innovator to capture the value of his or her invention upon success in the marketplace.

Technical inventions can be protected using patents, provided they meet the required patentability criteria in the relevant jurisdiction. Patents protect an inventor against competitors' using the invention without his or her authorization. At the same time, they constitute a vehicle for sharing technology, as well as access to explicit technical information about an invention. Patents can be bought and sold, licensed, sub-licensed, and cross-licensed.

Confidential business information, including customer lists, formulae, and undisclosed explicit and tacit knowledge, can be protected using trade secrets. Provided certain legal requirements are met, trade secrets protect against the misappropriation of proprietary knowledge (Brant & Lohse 2014b). Like patents, trade secrets can be licensed and cross-licensed. Often, patents and trade secrets are complementary and are licensed together in a hybrid licence that enables the licensee to fully understand and work the technology. As mentioned earlier, trust is central to the transfer of tacit knowledge, or know-how. The willingness of innovators to share their most valuable know-how can be enhanced through the enactment of legal frameworks, including trade secret laws, that provide recourse if know-how is misappropriated.

Licensing enables an entity, such as a firm or research institute, to obtain and use knowledge without having to invest in developing it, thus reducing cost and risk. Licences are critical tools used by firms and other innovators to share their technology and know-how. At the same time, they ensure businesses have "freedom to operate" and are not infringing on the rights of others. Licences state the terms of transferring a piece of knowledge from the seller or licensor, usually the owner of the relevant IPR, to the buyer or licensee. They set out the terms of transactions, including any royalties to be paid and limitations on use of the information being shared. Cross-licensing, which is reciprocal licensing between partners, enables innovative entities to access each other's knowledge (Bogers *et al.* 2011).

Licensing facilitates open, collaborative innovation and is thus one important channel for knowledge transfer (Brant & Lohse 2014a). In the biopharmaceutical sector, licensing is used from early stage research all the way through production. In-licensing is becoming more central to drug development, with an estimated one-third of molecules in stage III clinical trials now in-licensed (Gros 2009). Many promising solutions are in-licensed by leading biopharmaceutical companies from start-ups, which play an increasingly central role in this industry's innovative process (Gros 2009; Warcoin 2009). Patent licences are also critical in this sector to securing freedom to operate, and creating leverage in future technology transactions.

The ability to protect and share technology through licensing is grounded in the effectiveness of the IP protection system in a given jurisdiction (Bogers *et al.* 2011; Maskus 2012). When IP systems are strengthened, international technology transfer through licensing has been found to rise as risks and transaction costs are reduced (Park & Lippoldt 2005). More effective protection and enforcement of patent rights may induce technology suppliers to transition from exports to FDI and licensing, particularly in developing countries with greater imitative capacity, thus enhancing access by firms in such countries to technology and know-how. Recent studies have confirmed the correlation between improvements in IP protection and enforcement, on the one hand, and technology transfer through licensing, FDI, and trade, on the other hand (Maskus 2012).

With respect to trade, studies associate more robust patent protection and enforcement with higher import and export volumes of manufacturing and high technology goods in developing countries (Maskus 2012). As discussed, the importation of products embodying new technology and knowledge can provide opportunities for local researchers to study the technology through methods like reverse engineering. Reverse engineering and imitation represent one learning strategy for actors that are further away from the technology frontier, such as firms in developing countries. However, in the long run, firms or regions are unlikely to remain competitive without improving their ability to generate new knowledge and innovate (Dahlman 2010). Sustained improvements in absorptive capacity may require technological partnering with innovative firms, which can provide access to explicit technical knowledge as well as know-how (Archibugi & Pietrobelli 2003). Ultimately it is the local knowledge base, combined with “spillover knowledge” from outside actors, that influences a region’s ability to leverage its growing capacity for innovation to generate economic growth (Capello & Lenzi 2014).

Attracting technology flows – and, especially, technology partners – may require that a country upgrade its innovation framework. The level of IP (particularly patent) protection is one factor that influences investment decisions by foreign technology providers (Maskus 2012), since more effective protection and enforcement of IPRs enhance predictability while reducing risk. Technology suppliers report unwillingness to share their most valuable knowledge in countries without an effective IP system.

Policy Actions to Accelerate Technology and Knowledge Flows

Policymakers can support and enhance knowledge and technology flows by creating an enabling policy environment for investments in R&D and collaboration with local innovators, whether firms or research institutes. Above all, this means investing in absorptive capacity and ensuring a sound business environment. Actions considered best practices are those aimed at improving (Schiffbauer 2011; Autant-Bernard *et al.* 2013; Sonmez 2013):

- Human capital, including education and training;
- Openness of trade policies;
- Quality of infrastructure;
- Macroeconomic stability and the rule of law;
- Coherence and predictability of industrial and innovation policies; and
- Financial systems including access to finance for innovators.

The above actions, generally the responsibility of the central government, may be complemented by targeted actions by policymakers at the regional level to enhance knowledge flows and regional innovative capacity.

Based on the common features of successful regional innovation systems and clusters, several broad recommendations for regional innovation and cluster policies have been proposed in recent years. For instance, policymakers have been encouraged to invest in the creation of universities and other suppliers of R&D, and to establish platforms to encourage networking among public and private actors (Moodysson & Zukauskaite 2012). Promotion of networking is based on the rationale that more interaction could lead innovative actors to identify potential synergies and work together, thus boosting technology and knowledge creation and diffusion.

It is not enough to invest in the creation of new knowledge. New knowledge generated within a region or cluster must also be applied and utilized. Thus it is essential to attract the participation of innovative firms that can commercialize research results, including by ensuring that firms can recuperate R&D investments upon success in the marketplace (Ho *et al.* 2010). In addition, research points to the value of public services to support entrepreneurship and R&D, for instance financial services, coaching, and systems for the protection and enforcement of IPRs (Saxenian 2006; Doepfer 2012). Policies that address these types of specific needs at the firm level can help make the connection between R&D supply, networking, and knowledge spillovers, on the one hand, and the commercialization of innovation and positive impacts on regional growth, wages, and jobs, on the other hand. Initiatives that are targeted at stimulating behavioural change among individual actors may be more effective than broader programs, such as those aimed at creating a "culture of innovation", on their own (Moodysson & Zukauskaite 2012).

Evidence points to the need for "smart", or targeted, regional policies to attract knowledge flows and enhance innovative capacity. Such policies should: be designed in line with the specific characteristics and strengths of the region, be embedded in local context including the mix of local industries and their innovation patterns, and create strong linkages with external networks (Autant-Bernard *et al.* 2013; Capello & Lenzi 2014). Ho *et al.* (2010) identify the following actions that can be taken by policymakers to improve the capacity of a region or cluster:

- Invest in public knowledge infrastructure such as university networks;
- Create platforms for collaboration and exchange among innovative actors within the cluster or region;
- Provide public services required by the actors in the cluster or region, based on a needs assessment;
- Attract private firms to participate through appropriate incentives and development schemes;
- Support the establishment of linkages between firms and customers, partners, and other actors abroad; and
- Establish appropriate business frameworks and regulations.

In addition, policymakers can support regions in upgrading capabilities in their area of specialization and diversifying into additional areas of technology, to enhance resilience (Autant-Bernard *et al.* 2010; Clark *et al.* 2010). They can help to ensure their regions continue to evolve while avoiding technological lock-in, improving their chances of successfully innovating over the longer term (Autant-Bernard *et al.* 2010; Capello & Lenzi 2014; Clark *et al.* 2010) (Box 5).

BOX 5: Case Study of a Dynamic Innovative Region: Silicon Valley

Silicon Valley has a social and institutional setting that affects the firms in that setting while simultaneously being influenced by their strategies and structures. This industrial system can be considered to have the following dimensions: local institutions, industrial structure, and corporate organization. The region has a dense matrix of public and private institutions catering to the needs of local entrepreneurs. These institutions together contributed over time to the development of a technical community that builds upon shared laws and regulations, understanding, values, and norms.

The industrial structure of the Valley is vertically disintegrated. In other words, it is home to a social division of labour in which individuals' skills frequently combine and re-combine with the technical specializations of organizations. This vertical disintegration provides space for specialization across a range of activities related to computing. The corporate organization of firms has facilitated horizontal channels of communication between various local actors, including customers, suppliers, educational institutes, and competitors, based on formal and informal ties.

Its "network-based industrial system" is what makes Silicon Valley famously dynamic, allowing actors in the region to collectively experiment and learn. It also gives firms in the region the competitive advantage to meet and adapt to changing circumstances, and to take the lead in emerging technology-driven GINs. Geographical proximity is a necessary condition for intra- and inter-regional interactive learning and innovation to take place, since it shapes organizational, relational, and cognitive proximity. These forces, in turn, contribute to the formation of intra- and inter-firm and regional networks for collaboration and innovation.

Source: Saxenian (1994)

Conclusions and Recommendations

Summary

Technological innovation can provide new and more cost-effective solutions to public policy and other challenges. Technological advancement is a gradual, active process of learning that is embedded in the social context in which it takes place. The diffusion of technology and knowledge provides opportunities for regions and firms that are comparatively less developed to close the technology gap and to develop their own innovative capacity.

The type of knowledge – explicit, tacit – and the context in which it is being transferred influences the speed and impact of its diffusion and adoption. Adequate absorptive capacity is a critical prerequisite for the successful transfer of both explicit and tacit knowledge. The sharing of tacit knowledge, or know-how, is complicated, requiring sustained, direct engagement. Trust, which is crucial to tacit knowledge transfer, develops over time and can be reinforced by appropriate legal frameworks that provide recourse in the event that valuable know-how is misappropriated.

Technology and knowledge diffusion can be encouraged and accelerated by the right policy, market, culture, and other conditions.

Explicit and tacit knowledge are disseminated through a range of mechanisms and channels including trade and FDI, acquisition of IPRs, movement of skilled workers, knowledge spillovers, formal and informal networks, and regional innovation interactions. Increasingly, a range of public and private actors are combining resources and expertise in order to more effectively confront the rising costs, risks, and complexity associated with innovation. Firms in particular are embracing collaborative innovation models, offering new opportunities for entities located anywhere in the world to participate in global innovation networks.

Whereas in the past, knowledge was considered to flow primarily from developed to less developed regions of the world, today substantial and increasing South-South and South-North flows are observed. MNCs are pursuing opportunities in mature markets for offerings that were originally conceived of and developed with emerging market needs in mind. Overall, working with partners is critical to ensuring that solutions are appropriately adapted to meet conditions and needs in different locales.

Policymakers can enact enabling environments for technology and knowledge flows, including by improving systems for IP protection. IPRs facilitate the sharing of technical and other knowledge, thus underpinning collaborative R&D. Collaboration enables firms, universities, and other innovators to benefit from the knowledge of others without the financial burden or risk of developing the knowledge in-house – and to share their own research and solutions with partners who can refine and scale them. Effective systems for IP protection and enforcement are associated with more international technology transfer through trade, FDI, and licensing. More robust IP protection can contribute to securing technology partnering and thus access to tacit knowledge, enhancing absorptive and innovative capacity over time.

Recommendations for policymakers

Because each situation is unique, "one-size-fits-all" policy approaches are unlikely to be effective across regions for attracting technology and knowledge flows and ensuring they translate into enhanced innovative capacity, growth, and job creation. Moreover, while an appropriate policy environment may be a necessary condition for knowledge flows and technological catch-up, it is not in itself a sufficient condition, since some influential factors – location, size of market, social and cultural factors – are outside of policymakers' control.

Nonetheless, across the board, the following types of actions may improve absorptive capacity and the business environment, increasing the likelihood of attracting FDI, enhancing access to products that embody new technology, and increasing opportunities for technology partnering.

- Prioritize the creation of a sound, **stable environment for doing business**, including macroeconomic stability, rule of law, and removal of barriers to trade and investment;
- Invest in **physical infrastructure**, particularly in relation to communications, energy, and transportation;
- Invest in **public knowledge infrastructure**, such as universities and research institutes, and act to attract top scientific talent to research institutes. Fund public R&D in strategic fields of technology, to upgrade the knowledge base in those areas;

- Invest in **education and training of the work force**, from elementary through tertiary education, as well as specialized training for engineers and scientists; and
- Establish **incentives for private R&D investments** and collaboration, including effective protection and enforcement for intellectual property rights such as patents and trade secrets.

At the regional level, the following actions can enhance innovative capacity, through the provision of public services needed by innovators and the promotion of cross-fertilization of ideas among different public and private actors.

- Create platforms to **encourage innovation interactions** among public and private actors, and provide services required by firms and other innovators;
- Enact **targeted regional innovation strategies**, ensuring they are in line with regional competitiveness objectives as well as the features and innovation pathways of the region. Encourage inter- as well as intra-industry interactions;
- Encourage **patenting and licensing by universities** and research institutes, so that research outcomes can be developed and commercialized by partners;
- Assist innovators in the region to **upgrade specialized knowledge and diversify** into new technology areas, to avoid lock-in and enhance resilience; and
- Encourage **linkages between local innovation systems and international networks,** for instance by facilitating engagement by firms and research institutes with partners, customers, and knowledge networks abroad.

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Notes

THE INTERNATIONAL CHAMBER OF COMMERCE (ICC)

ICC is the world business organization, a representative body that speaks with authority on behalf of enterprises from all sectors in every part of the world.

The fundamental mission of ICC is to promote open international trade and investment and help business meet the challenges and opportunities of globalization. Its conviction that trade is a powerful force for peace and prosperity dates from the organization's origins early in the 20th century. The small group of far-sighted business leaders who founded ICC called themselves "the merchants of peace".

ICC has three main activities: rule setting, dispute resolution, and policy advocacy. Because its member companies and associations are themselves engaged in international business, ICC has unrivalled authority in making rules that govern the conduct of business across borders. Although these rules are voluntary, they are observed in countless thousands of transactions every day and have become part of the fabric of international trade.

ICC also provides essential services, foremost among them the ICC International Court of Arbitration, the world's leading arbitral institution. Another service is the World Chambers Federation, ICC's worldwide network of chambers of commerce, fostering interaction and exchange of chamber best practice. ICC also offers specialized training and seminars and is an industry-leading publisher of practical and educational reference tools for international business, banking and arbitration.

Business leaders and experts drawn from the ICC membership establish the business stance on broad issues of trade and investment policy as well as on relevant technical subjects. These include anti-corruption, banking, the digital economy, marketing ethics, environment and energy, competition policy and intellectual property, among others.

ICC works closely with the United Nations, the World Trade Organization and intergovernmental forums including the G20.

ICC was founded in 1919. Today its global network comprises over 6 million companies, chambers of commerce and business associations in more than 130 countries. National committees work with ICC members in their countries to address their concerns and convey to their governments the business views formulated by ICC.

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