Chapter 13

Global Knowledge Flows, Absorptive Capacity, and Capability Acquisition:

Old Ideas, Recent Evidence, and New Approaches

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Abstract

In this chapter, we reconsider the key lessons presented by more than two decades of empirical research on international knowledge flows. We begin by reviewing some of the key empirical findings and policy lessons from that literature. We then build on this review by pointing out the importance and uneven distribution across developing countries of absorptive capacity, which may help explain the uneven diffusion of knowledge across these countries. We also consider the implications of growing R&D globalization, the potentially declining importance of international manufacturing value chains, the rise of global trade in services, and the new opportunities opened up by AI-enhanced learning technologies.

# Introduction

We begin with a pair of fundamental observations. First, in an era of unprecedented global economic integration since the Second World War, extraordinary progress has been made. Despite contemporary undercurrents of discontent, the founders of the postwar economic order would surely be delighted to see the degree to which their vision of a world knit together by commerce was realized by the early 21st century. This era has made great contributions to human well-being, in large part a result of increasing diffusion of knowledge to the developing world.

Second, despite this progress the gap in incomes between the richest and poorest nations remains immense (Jones, 2014). While people in some major emerging countries have experienced considerable income growth, in much of the developing world that progress has been slow and uneven, leaving many millions in poverty (Collier, 2007). Growth economists point to persistent technological gaps between nations as the primary source of these large income gaps (Acemoglu, 2009). This situation begs the question of why technology has not diffused sufficiently to eliminate these gaps, or seems only to be doing so in particular regions. What unseen barriers could be standing in the way of universal technological convergence?[[2]](#footnote-2)

The language we traditionally use to describe these phenomena may itself be a source of misunderstanding. We speak of international “knowledge *flows*,” suggesting knowledge resembles a liquid that will easily and beneficently flow downhill in the absence of impediments. Indeed, the greater the gap in income (and technology) between nations, the more rapidly the liquid embodying knowhow should flow. Our terminology implies that all we need is a channel, like the ancient Roman aqueducts, and open receptacles in poor developing countries, and gravity will do the rest. This appealing metaphor makes it easy to understand how critics of market-led globalization might conclude that some infernal barrier, set up by the currently rich nations, is somehow impeding the natural flow of knowledge. The Northern insistence on stronger intellectual property rights (IPRs) is often viewed in this light.

Unfortunately, this physical metaphor is highly inaccurate in describing how knowledge really flows across countries – or more often fails to do so. The truth is that economically valuable knowledge is “sticky,” often at least partly tacit (Polanyi, 1958), and resides principally in human beings. In one of the earliest studies of international technology transfer within multinational firms, Teece (1977) pointed to the surprising difficulty of moving knowledge across national boundaries, even within the same enterprise. Successful transfer of technology requires the acquisition of capabilities both by the transferor and transferee (Sutton, 2000). It requires an expensive investment by the receiving party in absorptive capacity (Cohen and Levinthal, 1989, 1990; Arora and Gambardella, 1990, 1994). It also often requires the willing, active cooperation of the parties possessing the knowledge.

Crucially, the successful acquisition of frontier technological knowledge often requires the prior mastery of more basic knowledge and skills, a cumulative process. Finally, successful technology transfer requires coordinated capabilities among many individuals. When we consider the scale and complexity of the human capital investment required to support international “knowledge flows,” the mystery of its difficulty begins to fade.

In this chapter we reconsider the key lessons presented by more than two decades of empirical research on international knowledge flows – a scientific enterprise in which we have both actively participated. Our point of departure is to place context around the disparities in the emerging and developing world between those countries with sufficient size, economic dynamism, and the necessary complementary skills to learn deeply from the global stock of knowledge, and those countries without such advantages. The insights gained help explain why the income and productivity gains from information globalization do not diffuse as widely as basic models would suggest.

We begin in Part 2 by reviewing briefly the primary empirical results and policy lessons from recent literature. We also highlight ongoing research questions that are expanding our understanding of key questions. In Part 3 we turn to the important question of how R&D investments have been globalized, primarily by multinational enterprises (MNEs), and the implications for knowledge flows. With this background, in Part 4 we discuss the crucial role played by investments in human capital and the acquisition of technological capabilities in technology-receiving countries. In this context, we emphasize the important work of Jones (2014) regarding the nature of human capital in absorbing and improving knowledge. In particular, his work emphasizes that knowledge acquisition and use increasingly require complementary technical skills within an economy. Achieving broad skill endowments may not be feasible in poor countries for some time, suggesting that investing in deeper skills that may be deployed in global information networks could be a better development strategy. We also draw lessons from interesting experimental work aimed at improving education delivery in India through the use of artificial intelligence (AI). Together, these insights point to the need for a broader understanding of how knowledge is transmitted and could be better absorbed in the current era. We draw policy inferences in Part 5.

# How Does Technology Move Across Borders?

## Technology Diffusion: Channels and the Role of IPRs

For most developing economies, accessing and deploying international technologies is the primary source of new information, productivity gains, and economic growth (Keller, 2004). International technology diffusion is therefore a major determinant of global technical change and increasing such flows is a critical part of development policy. It is equally vital to adapt technologies to local conditions and learn how to use and improve them. Countries seeking access to foreign technologies therefore build into their innovation systems the entire policy complex involving skill accumulation, investment, competition, R&D support, and intellectual property rights.

It has long been recognized that an important channel of acquiring technological information is trade in high-technology goods and services (Coe, et al, 1997). Imported capital goods and technical intermediate inputs can directly improve productivity by being placed into production processes. A second is foreign direct investment (FDI), by which multinational enterprises (MNEs) transfer to their subsidiaries newer and more productive technological information (Markusen, 2002). MNEs often indirectly increase local productivity through sharing with upstream suppliers best standards in producing intermediate inputs (Javorcik, 2004). Yet a third is technology licensing, which typically involves the transfer of production or distribution rights and the associated technical information and know-how. A fourth is the cross-border movement of engineers and technicians (Hovhanissyan and Keller, 2015).

One important factor determining how readily technologies may be diffused through these various channels is the scope of IPRs in recipient countries. On the one hand, patents, trademarks, and enforceable contracts for licensed trade secrets can reduce the information costs and uncertainty of technology transfer (Hoekman, et al, 2005). They can also limit the tendency of recipient firms to expropriate technology opportunistically (Antras, 2005). On the other hand, if patents have extensive scope, say through broad claims and a ban on experimental use, they can make it more costly for domestic firms to imitate foreign technologies.

Recent empirical evidence suggests that technology movements to emerging and middle-income economies are generally enhanced by IPR protection. For example, in the first study of the trade impacts of TRIPS reforms, Ivus (2010) analyzed the growth of high-technology exports from 24 OECD countries to 55 developing countries. Taking the 18 countries with larger policy reforms as the reference group, she found that high-technology exports to those nations grew significantly faster than low-technology exports., The stronger patent rights increased the value of OECD exports of patent-sensitive goods to those countries by 8.6 percent. More recent studies find strong evidence that such reforms also raise the exports of high-technology goods from middle-income economies (Delgado, et al, 2013 and in this volume). This result suggests that such countries are able to incorporate foreign technical information into greater production of exportable goods. Maskus and Yang (2018) also found a pro-export impact and showed that potential sources of this learning include inward patent applications, incoming FDI, and intra-firm trade in high-technology intermediates.

Regarding FDI, recent evidence suggests that IPR reforms could affect multiple activities of MNEs. One prominent study analyzed the impacts on licensing of U.S. parents with affiliates after patent-law changes in 16 emerging economies (Branstetter, et al, 2006). The authors found that royalty payments to parents rose by 34 percent on average, mostly reflecting an increased volume of technology sold rather than higher royalty charges. There was also a significant increase in R&D investments at local subsidiaries. Both of these effects were much stronger in high-technology industries.

A related analysis found significantly positive increases after patent reforms in affiliate sales, net plant and equipment, and employee compensation among affiliates of U.S. MNEs (Branstetter, et al, 2011). Further, they found that value added in local firms rose significantly, especially in technology-intensive sectors. There was also strong evidence that firms in these countries expanded the range (or “extensive margin”) of products exported to the United States after patent rights were broadened.

To summarize, the best available evidence supports the claim that patent reforms have positive effects on inward technology transfer through market-based channels. They raise imports of high-technology goods and may also stimulate export growth. Stronger IPRs expand the local activities of multinational firms, while increasing licensing to both affiliated and unaffiliated parties. They particularly stimulate such responses among high-technology firms.

While these are important benefits, they must be qualified. First, to date these impacts have been found only in larger and middle-income countries. There is little evidence of such effects in the poorest and smallest developing economies, where the limited amounts of technology transfer render patents of little relevance. Second, to date there are no serious studies of any potential restrictive impacts of IPR reforms in poor countries. Local firms may have to change product lines or close down if they cannot adapt to the new competitive environment post-reforms, a possibility about which systematic evidence is absent. Finally, the available measures of technology diffusion are indirect and may miss considerable amounts of formal and informal knowledge transfers.[[3]](#footnote-3)

Despite the flaws in data, it does seem that there has been little supply response in much of the developing world, even as developing countries have adopted stronger IPR protection. Put differently, formal technology markets are unresponsive to such reforms in poor countries, while updated legal regimes have had little detectable impact on domestic technology use or adaptation. This observation may puzzle advocates of strong global IPR protection but, as we argue later in the chapter, it largely reflects the lack of absorptive capacity and complementary human skills in such societies.

## The Rise (and Possible Fall) of Extensive Production Networks

We consider briefly a special case of FDI and trade that embodies considerable technology sharing and diffusion, the development over the last few decades of extensive global and regional supply chains. Baldwin (2016) discussed the ability of multinationals to separate even narrow stages in the vertical production chain of many products and to place those stages in various locations. This second great “unbundling,” in this case of production stages from one another and from headquarters services performed in the home country of an MNE, was facilitated by the emergence of sophisticated information and communication technologies (ICT), trade and investment liberalization in emerging economies, and reductions in shipping costs. A canonical example of this fragmentation is the North American automobile industry, which developed sharp specialization by stages of production across the member countries of NAFTA. Other industries that developed extensive international production chains include microelectronics, household appliances, textiles and apparel. The remarkable growth in trade involving such networks may be seen in the rapid increase in international value added embodied in the exports of increasingly interlinked economies.[[4]](#footnote-4)

The dramatic outsourcing of production stages created significant amounts of manufacturing jobs in those developing countries that established linkages to global value chains. This is the essence of the early stages of China’s industrial transformation, while manufacturing employment grew rapidly in Vietnam, Indonesia, Mexico, Poland, and many other emerging economies. A similar statement would apply to the development of tradeable services in India. For such countries the rapid growth of such sectors and networks constitutes the major economic development story of our time.

Some of the more labor-intensive stages in supply chains may be described as shallow and footloose, with relatively little effective technology transfer (Baldwin and Lopez-Gonzalez, 2013). However, production chains often involve trade in sophisticated intermediate inputs, investment in new capital goods and processes, and procurement of locally produced inputs. In this context, because final goods must be produced with reliability and quality, MNEs at the center of networks cannot risk being exposed to shoddy inputs, varying production standards, and indifferent assembly. Such firms, therefore, find it important to transfer their best technological information, insist on high-quality process standards, and demand timely deliveries. In turn, a distinctive feature of global and regional value chains is the purposeful sharing of technological knowledge among network partners.

Evidence suggests that the emergence of these complex supply relationships undergirds both the transfer of manufacturing employment and the diffusion of technology to emerging nations (Baldwin, 2016; OECD, 2017). Indeed, it seems that industries in countries that are closely linked to international value chains become more innovative, as measured by foreign patent applications (Piermartini and Rubinova, 2018, and in this volume). However, this same literature points out the clear importance of partner countries investing in human capital and appropriate skills on the part of the domestic workforce in order to achieve such gains. We emphasize this again in the following section on the internationalization of R&D spending and teams.

Thus, the employment, productivity and knowledge gains from integration with supply chains have been significant in the emerging world. Whether this process may spread to more developing countries is increasingly debatable, however. A primary caution, as we discuss below, is that the impending explosion of AI technologies in manufacturing portends even greater replacement of lower-skill manufacturing and service jobs, including in poor countries.

# The Globalization of R&D

## The Fundamental Need for International Research Collaboration

One focus of the literature on global knowledge flows has been on what might narrow the technological gap between developed and developing economies. This gap would necessarily close faster if the developed world experienced a profound and persistent slowdown in the rate of innovation. Could this ever happen?

For most of the postwar period, productivity growth in the Western countries, Japan, and the rest of industrial East Asia seemed robust enough that economists believed in a sustainable innovation process that would support income growth forever. The idea arose from the “endogenous growth” concepts of Romer (1986, 1988), Aghion and Howitt (1992), and Grossman and Helpman (1990, 1991). The basic idea was that R&D efforts would combine with a growing pool of knowledge, sustaining high returns to R&D investment forever. This faith was reinforced in the mid-1990s as, at least in the United States, there was a pronounced acceleration of productivity growth driven by the diffusion of ICT.

At the same time, however, younger growth economists questioned the view that the technological frontier was really endless. Jones (1995a, 1995b) pointed out that, despite rising research intensity in Western economies, there were flat or declining productivity growth rates outside the ICT sector. He developed several “semi-endogenous” growth models, in which various factors might prevent increases in R&D from permanently raising the innovation rate. Kortum (1997) came to similar conclusions, suggesting that within particular knowledge domains there were a limited number of good ideas and that, once these had been harvested, diminishing returns to R&D would set in.

Jones (2009) again made a significant contribution, modeling a plausible mechanism that would reduce the productivity of research effort over time. The knowledge base upon which human inventors build is constantly expanding. However, human inventors must first master the knowledge built up by previous generations before they can extend it, a daunting task in today’s economy. Human technological knowledge is so vast that even the brightest individuals can only reach the frontier, after years of advanced education, by specializing in a narrow piece of that knowledge. Unlike the past, successful invention today increasingly requires the bringing together of complementary pieces of frontier knowledge. In turn, successful innovation requires ever larger teams, with associated costs of coordination. In essence, the mountain of knowledge is rising, but each new generation has to start at the base. The patterns of collaboration suggested by the model in Jones (2009) have been confirmed by evidence in patent documents (Branstetter et al., 2008; Branstetter et al., 2015).

In the wake of the global financial crisis, it became increasingly evident that the rate of productivity growth in the U.S. and other developed economies has slowed sharply (Byrne et al, 2016). Jones’ work suggests that even if the current wave of digital innovation brings a boost in productivity growth, it will be a temporary reprieve from a looming fundamental slowdown in innovation arising from this “burden of knowledge”. A more lasting escape would require a transformation of human capital formation or the structuring of knowledge, so that new innovators can rise from the base of the mountain to its peak much more quickly. This would entail better understanding of interrelationships between bodies of knowledge, a task that makes the formation and management of ever larger teams more effective. Alternatively, it would require a large increase in the number of intelligent individuals willing to engage in innovative work that can be purchased or shared without raising the costs of innovation.

## From the Product Cycle to International Co-invention: Innovation in the Global South

International economists have long studied the “product cycle,” in which a manufactured good would be invented and initially manufactured in the most advanced industrial economies (Vernon, 1966). Over time, production would shift to less advanced economies as the technology embodied in the product became more standard and routine. Theoretical work on the impact of IPR reform in developing countries put this notion of a product cycle at the center of a stylized model of the global economy with an industrialized “North” and a developing “South.” Important early research by Helpman (1993) developed several variants of a North-South general equilibrium product-cycle model in which Northern innovation expands the range of differentiated goods produced in the world while Southern imitation leads to North-South production shifting.

Lai (1998) extended Helpman’s model to allow both the level of FDI and Northern innovation to respond to changes in the strength of Southern IPR protection. This model is further extended in work by Branstetter and Saggi (2011) to the case where innovation, FDI, and imitation are all endogenously determined – in other words are all determined within an economy. In these extensions, in any equilibrium with a positive rate of imitation, North-South FDI does not lead to equal wages in the two regions. A lower wage in the South creates an incentive to move production of existing varieties there, but MNEs doing so through FDI incur a higher risk of imitation when they move production to the South.

Imitation is a costly activity that requires deliberate investment on the part of Southern firms seeking to copy Northern products. Stronger IPR protection in the South increases these costs, reducing imitation and lowering the risks faced by MNEs. Production shifting allows for a reallocation of Northern resources towards innovative activity. Under certain assumptions, a strengthening of Southern IPR protection enhances Southern industrial development because the increase in North-South FDI more than offsets the decrease in Southern imitation.[[5]](#footnote-5) To the extent that empirical work on global knowledge flows has been guided by general equilibrium trade models, the international product cycle model has been the most influential.

Obviously, these models assumed that innovation was concentrated in the “North.” This remained a reasonable assumption through the 1990s, given the enduring concentration of R&D expenditure and patenting in the developed countries.[[6]](#footnote-6) However, that long-standing truth is now changing, driven in part by the significant rise in human capital outside of the Western world.

This rise is perhaps most pronounced in China and India, though growth in R&D expenditures and patenting is visible elsewhere in the developing world. Indian and Chinese students combined earned 18% of doctorates in science and engineering from U.S. universities in 2016.[[7]](#footnote-7) At home, China graduates more than four times as many bachelor’s-level engineers as the United States. China’s participation in international comparisons of student achievement suggest that its educational system meets reasonably high standards for a developing country at China’s income level.[[8]](#footnote-8) Applications from Indians made up 62% of new H-1B visa applications in 2016,[[9]](#footnote-9) and the rapid expansion of Indian engineering schools has been documented by Arora and Gambardella (2005). If we view the large number of Indian and Chinese students pursuing graduate education at American research universities as the extreme right tail of a distribution of science and engineering talent, most of which remains at home, then this suggests a massive amount of human capital is available in China and India. This factor has surely accelerated the development of advanced capabilities in manufacturing and modern services work, allowing China and India to become such successful exporters of manufactured goods and services, respectively.

The impact of this human capital accumulation on the global distribution of innovative activity is harder to judge. Within China, there has been sharp growth in R&D spending and an explosion of patenting. China now grants more invention patents to domestic inventors than any other patent office in the world. These raw numbers suggest a rapid shift in the locus of global innovative activity toward the South, and to China in particular. It must be noted, however, that specific government edicts and subsidies designed to reward patenting explain some of this trend. There is also evidence that the novelty standards required for a patent grant in China have fallen (Branstetter, et al., 2015; Branstetter, et al., 2018).

Researchers traditionally have used the propensity of inventors to take out patents in multiple countries as a measure of patent quality. U.S. firms tend to apply for foreign patents for about 50% of their domestic inventions, and around one third of U.S. patents eventually obtain a grant in at least one other country (Branstetter, et al., 2015). Impressive though China’s “Great Wall” of patents appears to be, the fraction of these inventions for which domestic Chinese inventors seek foreign patent protection is small. For only about 5% of domestic patent applications do Chinese inventors even go through the trouble of applying for protection abroad, and the fraction of Chinese patents that have been granted in foreign jurisdictions is only about 1-2 percent of the total (Branstetter, et al., 2015), although these numbers may have changed since this study.

Analysis of the international patents granted to China-based inventors and India-based inventors reveals the disproportionate role played by multinational corporations in channeling the efforts of inventors based in these countries into new patented inventions. Branstetter, et al. (2015) show that, through the mid-2010s, a majority of patents with at least one inventor located in India or China at the time of patent application are assigned to a MNE based outside those countries. Interestingly, a large fraction of these patents is generated by teams of inventors with addresses in multiple countries. Branstetter, et al. (2015) refer to this as international co-invention, and suggest that international teams provide a unique way of combining high levels of “raw talent” in emerging economies with the complementary skills necessary to generate frontier innovation.

## The Role of Multinationals in an Era of R&D Globalization

Jones’ (2014) model of the “knowledge trap” points to the challenges facing MNEs that seek to generate new innovations solely through the efforts of indigenous inventors in developing countries. Frontier innovation requires a suite of specialized skills, not all of which are embodied in the local staff. Branstetter, et al. (2018a) provide an alternative, simpler model of the same idea. Prior to the advent of the internet, and the diffusion of software-enabled engineering design tools that can facilitate collaboration among geographically distant co-inventors, the limited skills and experience of local inventor teams in developing countries strictly limited the degree to which they could participate in the advanced innovative activities of global firms. To be sure, complementary skills exist elsewhere within the MNE, but before the advent of the global internet, the “high-bandwidth” information sharing required among members of an inventor team effectively required that seasoned researchers resident in advanced industrial countries be dispatched, often for long periods, to emergent R&D centers in developing countries or vice-versa. Either movement was expensive for the employees and the enterprise. It is therefore not surprising that, in the pre-internet era, relatively few patents had international inventor teams, and very few of those contained significant numbers of inventors based in developing countries. It is especially interesting to note that, even as the number of U.S. patents granted to Taiwanese and South Korean inventors shot up in the late 1980s and 1990s, very few of these patents contained non-Taiwanese or non-Korean inventors.

Modern ICT has therefore played a critical role in facilitating international R&D collaboration. Now, talented young engineers in a developing country no longer need to possess the full suite of capabilities necessary to engage in frontier research. Instead, they can specialize in a subset of these capabilities, and “import” the rest by collaborating with team members based in developed countries. Using the comprehensive database on U.S. MNEs maintained by the U.S. Bureau of Economic Analysis, Branstetter, et al. (2018b) document a sharp rise in the share of emerging markets in U.S. MNE R&D expenditure and patenting that is coincident with the diffusion of these technologies. Interestingly, this shift is not uniform across industries. ICT itself plays an important role in this growing globalization of R&D. Branstetter, et al. (2018b) present evidence consistent with the view that ICT innovation is more “modular,” meaning that innovation in components of a system can take place more or less independently. This is because standard interfaces and system architectures allow independently developed ICT hardware components (or bits of software) to interact effectively with one another. It is also true that software-based engineering tools are especially well developed in these domains. Finally, the growing importance of software and ICT as drivers of innovation across multiple industries has created a shortage of engineers in advanced countries, which has prompted U.S. multinationals to take special advantage of the growing numbers of engineers available for hire in developing countries.

Branstetter, et al. (2015) document the disproportionately important role played by MNEs in generating the international patents assigned to Chinese and Indian inventors. They also show a significant quality difference between MNE-guided invention and the patents of domestic companies based on forward citations. Interestingly, this quality gap does not seem to fade over time. On the other hand, the authors document the striking degree to which the quality of invention generated by all-Chinese inventor teams employed by a multinational firm has converged to the quality of invention generated by inventor teams based in the MNEs’ home countries.

Branstetter, et al. (2018b) point to a potential mechanism by which this convergence in quality can be achieved. They observe that when MNE affiliates begin conducting R&D in a new technical domain, the number of inventor-team members based in advanced countries tends to be high. As this research program proceeds, the fraction of advanced-country inventors declines. The authors take this as evidence suggesting that repeated international collaboration is a mechanism of transferring specific knowledge from the MNE’s central R&D facility (or more advanced nodes in its network) to the relatively new hubs based in developing countries.

In light of the concern that insufficient human resources in the industrialized nations could bring about a long and substantial decline in the global rate of innovation, the “bridging function” played by MNEs is a potentially critical one. It could take decades for today’s emerging markets – let alone the poorest countries – to develop the full complement of skills required for frontier innovation. MNE-mediated international inventor teams relax that constraint, allowing the increasingly large numbers of engineers with high levels of basic skill and talent emerging from the universities of developing countries to join a truly globalized R&D system that connects them to the complementary skills they need to be productive. Indeed, MNE-based global R&D networks could accelerate the global rate of innovation or, at least, limit its decline. In the long run, the MNE-employed engineers in developing countries will acquire a fuller complement of skills, enabling some of them to form their own innovative teams.

The policy environment required to encourage the development of MNE-centered R&D networks seems clear enough. First, developing countries must educate their citizens up to the level that they can usefully contribute to such networks. This is a challenge with which many developing countries struggle, and where new learning technology may play a constructive role. We address that in the next section. Second, developing countries need to offer a stable and attractive policy environment for MNEs that includes a commitment to global openness and transparent protection of intellectual property rights. Third, and importantly, the governments of developed countries need to view the emergence of these networks as a source of benefit, not a “hollowing out” of internal innovative capacity.

# International Knowledge Flows in the Age of AI.

## A New (Post-) Industrial Revolution?

Until recently artificial intelligence was viewed as an esoteric branch of engineering with immense theoretical promise but enormous practical challenges, with little in the way of tangible results. The decisive turning point came in the 1990s, with the rise of “machine learning” as the increasingly dominant approach within AI.

This approach largely bypassed efforts to fully codify the rules of human decision making. Instead, statistical algorithms were developed that allowed computers to construct their own decision-making “rules,” provided they reproduced human judgments with high fidelity. With massive data sets, algorithms were soon capable of approaching human levels of accuracy in image recognition and speech to text translation. These advances opened the way for autonomous vehicles and conversational digital assistants. Related algorithms were able to detect anomalies and find heretofore unrecognized patterns in large, complex data sets, opening up the field of big-data analytics.

The ability of algorithms to learn from and find patterns within enormous data sets grew as ever larger amounts of data were captured by the internet. This process went into overdrive with the rise of “cloud computing,” the rapid diffusion of powerful handheld devices that allow billions of people to be connected to the internet, and the so-called “internet of things” that increasingly links devices to the internet (Gubbi et al, 2013; Regalado, 2014). With the rise of machine learning, the petabytes of data collected on the internet could now be sliced and diced with increasing ease and sophistication.

The expanding universe of smart devices, monitoring their own performance in real time under all the unpredictable conditions that obtain in the real world, effectively turns the entire planet into an information laboratory, generating reams of data that can be used in the next generation of (software-enabled) product development. Picking through these data to find salient patterns requires ever more powerful machine learning, AI, and large-scale data analytics. It also brings in a completely new engine to drive technological progress in the design of new industrial and consumer products.

This engine is also driving innovative progress in a growing range of personal and business services. An ever-greater fraction of human life in advanced countries is conducted online. Business services are increasingly internet-enabled, digitally-driven activities, offered via mobile devices to a global client base. For the first time in history, a large part of the service economy is now subject to the same kind of meticulous measurement as activity on the factory floor became in an earlier age. The exponentially growing domains of data, and the expanding opportunity to run “experiments” in real time, provide a new resource for the efficient creation of new and better products and services. This opportunity extends far beyond the conventional boundaries of manufacturing. Industrial firms have now entered a new era that fundamentally transforms business across the economy (Brynjolfsson and McAfee, 2014).

## The Decline of Manufacturing Employment in the Digital Age

Improving machine learning, along with the agility of robotic hands, imply that a new wave of manufacturing automation is likely to come, and may already be here. Increasingly automated assembly lines are less likely to travel across borders in search of inexpensive labor and, even when they do, they will bring fewer jobs for human workers. This has significant implications for traditional channels of international technology transfer. The preceding sections have highlighted the important role played by FDI, the unbundling of manufacturing value chains, and the creation of supplier linkages connecting indigenous manufacturing firms in developing countries (and their workers) to foreign purchasers with a well-developed understanding of advanced manufacturing. As manufacturing’s share of employment declines throughout the world, this traditional channel of knowledge transfer will become necessarily less important. Development strategies based on the attraction and expansion of local manufacturing will need to be rethought.

A growing literature has pointed to emerging signs of “premature deindustrialization” (Rodrik, 2016). In many cases, these changes are not the result of a policy failure, but rather reflect global shifts in the technology of production. While manufacturing firms will adapt their technology of production to reflect local factor prices, the rapidly growing capabilities of machines are likely to accelerate the pace at which advanced technology is incorporated into production, even in relatively poor countries. In this case, “technology transfer” may increasingly limit the ability of traditional channels to foster the local development of human capabilities. As this trend unfolds, its force will be complemented by the likely slowdown of the shift of manufacturing from advanced to developing countries. Baldwin (2016) provides a comprehensive description of the unbundling, but makes clear that this process has natural limits. Once all the manufacturing that was “movable” from the leading nations of the West had been moved, the spectacular growth in intermediate goods trade that has characterized recent decades would logically slow.

## A Rise of Digital Services Trade?

While AI and its assorted technologies are likely to accelerate the decades-long shrinkage of employment in manufacturing, the advance of ICT could power substantial growth in international services trade. Recent studies have pointed to the rising importance of business services exports for the United States and other advanced industrial nations (Jensen, 2011; *Economic Report of the President*, 2012). Thanks to advances in digitization, modern telecommunications, and the convenience of international air travel, an increasing array of business services can be exported to foreign clients. Available data strongly suggest that international trade in business services has grown rapidly and that they play a major role in the expanding services trade surplus of the United States.[[10]](#footnote-10)

Services exports, as measured in the official data, have expanded dramatically, doubling between 1997 and 2007, and resuming rapid growth after the global financial crisis. Services exports now account for nearly 30% of U.S. exports. This growth was disproportionately driven by business services, broadly defined. Despite this rapid growth, the measured export intensity of even the most theoretically tradable parts of the service sector remains far lower than in manufacturing. According to recent disaggregated data from the Census Bureau analyzed by Jensen (2012), the ratio of exports to sales in tradable business services is between 90% and 78% lower than in manufacturing. This lower ratio reflects a number of factors, including pervasive market access barriers in important trading partners that are considerably more restrictive than most remaining tariffs on trade in goods. It also reflects the reality that the ICT revolution making services increasingly tradable is still relatively recent and exporters around the world are still catching up to the possibilities it has opened up. Nevertheless, it is probable that business services and other ICT-supported services will eventually become as intensively traded as manufactured goods.

While this analysis is based on U.S. exports trends, the benefits of a substantial increase in business services trade will be global. Further, the impact on welfare may be greatest in developing countries where the quality and availability of business services is most constrained. Interesting evidence on this point comes from a randomized experiment in India (Bloom, et al., 2013). Researchers randomly selected a set of Indian textile factories to receive a complimentary five-month program of consulting services from a leading international firm. Upon arriving in these factories, the researchers and consultants found that productivity was hampered by poor management practices. Over the next five months, the consultants worked with the firms to implement successful management practices used in the West. When the project ended, the "treated" factories had cut product defects in half, substantially reduced inventories, and increased output, while the control factories saw little change. The authors calculated that profit increases of the treated factories resulting from these performance improvements exceeded $200,000 per year.

Given the magnitude of the improvement, why had the firms not adopted these practices earlier? The authors' results suggest that informational barriers were the primary factor explaining the lack of adoption. What is true for India is likely to be true throughout the developing world. By reducing barriers to trade in services, developing countries can help their own firms move towards the productivity frontier achieved in the West. By increasing the range of and quality of services inputs that could be imported, developing country firms can increase their productivity. In fact, these gains would be analogous to the positive impact of enhanced market access to imported capital goods and industrial intermediate inputs on emerging market firm growth and productivity documented by many studies (e.g., Goldberg et al., 2010).

A related possible source of developing country gains from services trade is highlighted in Jones (2014). This paper shows how the incentives of firms in developing countries to invest in specialized human capital can be reduced when the local stock of complementary specialists is limited. Jones notes that MNEs could, in principle, link specialists located in different countries together in production or development teams that could coordinate their effort in real time. This raises the incentives for investment in specialized human capital wherever these international networks exist. Expanding international services trade should facilitate development of international value chains in services industries, and that creates a broader range of sectors in which the “knowledge trap” can be ameliorated by globalization. Thus, while the rise of AI may reduce learning opportunities through the reduced importance of manufacturing value chains, it may help increase learning opportunities by supporting the emergence of globalized services value chains.

Those opportunities will only be realized if contemporary concerns over data privacy and the global reach of the largest digital services companies can be addressed without unnecessary impediments being placed on the global flow of data and the scope of operations of the best digital services providers (Branstetter, 2016). China is perhaps the world’s most open large developing country when it comes to trade in conventional goods, but arguably is the most “digitally protectionist” major economy in the world. Continued erosion of pro-digital-trade norms and practices could be as injurious to global welfare as the trade wars of the 1930s.[[11]](#footnote-11)

## AI and Human Capital Formation

Among the most exciting potential applications of AI are the prospects for machine learning to amplify and accelerate human learning. This essay began with a strong emphasis on the role of human capital constraints as a barrier to international knowledge flows. These barriers have remained significant, despite the impressive progress many emerging and developing countries have made recently in improving school enrollment and completion rates. This paradox arises partly because enrollments and graduations are not the same as learning. A growing body of evidence suggests that the productivity of developing countries in converting investments of time and money in education into real human capital remains low (Hanushek and Woessman, 2015). For instance, in India, over 50% of students in Grade 5 cannot read at the second grade level, despite primary school enrollment rates over 95% [(Pratham,](#_bookmark80) [2017).](#_bookmark80) Further, there have been limited improvements in learning outcomes in the past decade despite substantial increases in education spending [(Muralidharan,](#_bookmark72) [2013).](#_bookmark72) The low return on conventional investments in education raises the distressing possibility of human capital barriers that can never be lowered at a politically feasible price, permanently stunting growth and development.

In this context, it is useful to mention the recent work of Muralidharan et al. (2018).[[12]](#footnote-12) These authors present experimental evidence on the impact of AI-driven computer-aided learning software on the learning of a sample of Indian school children randomly selected into a supplemental instructional program using an AI-based instructional software. The authors find that students in the treatment group scored significantlyhigher in math and Hindi language relative to other students. The learning gains were achieved at a lower cost per student than in the public schooling system. Moreover, in earlier work, [Muralidharan](#_bookmark71) [(2012)](#_bookmark71) found that providing performance bonuses to teachers also led to significant test-score gains.

A key feature of the experimental software is its ability to use the ever-growing volumes of data generated by the students interacting with it to benchmark the learning level of every student and dynamically customize the material being delivered. A second noteworthy feature is its ability to analyze data to identify patterns of student errors and precisely target content to alleviate learning problems that may be difficult to address in the classroom. The ability of the software to personalize learning is critical because of the extreme heterogeneity the authors find among their students in terms of content mastery.

The software studied by Muralidharan et al. is just one example of a wave of AI-driven computer-aided learning systems that have been shown to generate significant learning gains. In the United States, Kenneth Koedinger has led an effort to develop similar systems, focused on mathematics. Large-scale randomized control trials conducted in the U.S. have shown that these computer tutors can substantially accelerate student learning (Pane, et al. 2014).   For decades education researchers have thought that small-group tutoring generates the best learning conditions possible but have struggled to solve the key challenge that small-group tutoring by regular teachers is “too costly for most societies to bear on a large scale” (Bloom, 1984).  AI-driven computer learning systems may offer the best chance yet of achieving this “first-best” approach to learning on a global scale and at a politically feasible cost. If so, the set of potential innovators available for emergent knowledge and innovation networks could be vastly expanded.[[13]](#footnote-13)

# Conclusion

In this chapter we have set out a number of points to help guide thinking about the present and future of international knowledge flows. We noted the importance of international trade, FDI, licensing, and global value chains as formal mechanisms of technology transfer and their sensitivity to local economic and social conditions. To a significant degree, however, these channels are being complemented by the growth of MNE-centered R&D networks that actively build international research teams. Indeed, there are reasons to anticipate the shift in manufacturing employment to developing countries to moderate, with activity shifting toward services and other knowledge-based activities over time in those countries that are prepared to participate.

In this context, the language we typically use to describe international knowledge “flows” downplays the significant investments in specific human capital required to transfer advanced capabilities from a set of firms and individuals located in a developed country to a different set of firms and individuals located in a developing country. Firms and individuals can only make these investments profitably when they are already equipped with an appropriate level of prior knowledge, and we suggested that the uneven geography of convergence can be explained, in part, by large gaps in knowledge capital across countries. These gaps are far larger than commonly measured school enrollment statistics would suggest. Jones (2014) makes a compelling case that the real variation in human capital may be sufficiently large to explain global differences in incomes and growth performances.

This view helps explain the limited degree to which the conventional mechanisms of international knowledge transfers have supported technology diffusion in recent decades, at least to areas beyond China, India, and other major emerging economies. Foreign firms will only transfer advanced technology to their subsidiaries where the skills of the local workforce and the level of sophistication in supplying and purchasing industries make that transfer profitable. Likewise, they will only invest in the capabilities of their local suppliers when the technology gaps are not too large. The measured effect of local IPRs (and other policies) on the actual incidence of technology transfer tends to be highest in the richer developing countries because these are the sites where the local skill level supports a significant degree of technology transfer. In the poorer developing countries, the low level of absorptive capacity among local firms and workers makes the *de jure* level of IPR protection less relevant.

If that argument is valid, then the pathway to a more equitable income distribution is clear – accelerate human capital formation in developing countries. Heretofore, that worthy goal has seemed all but impossible, given the limited resources available to developing countries to invest in their young and the remarkably low productivity with which those resources have been converted into economically valuable skills in those countries. However, new developments in technology – especially AI-driven computer-aided learning systems – may have brought us a powerful new tool with which to address the fundamental impediments limiting global knowledge flows and convergence. The new tools may well prove to be more limited in their capabilities and more subject to challenges than our early hopes suggest. Nevertheless, the promise suggested by recent research should compel the attention of policymakers and encourage efforts to exploit an important opportunity.

However, technology alone is likely to prove insufficient. While AI-driven learning systems may accelerate the formation of basic human capital in developing countries, these technologies will not eliminate the challenge developing countries – especially smaller ones – face in acquiring the full range of specialized skills an ever more sophisticated global economy will demand. But rising levels of international services trade could lessen this challenge by allowing developing countries to specialize in subsets of these capabilities, effectively importing the rest. This chapter has stressed the degree to which advances in information technology may enable a growing degree of international trade in knowledge-intensive services. This will create new export opportunities for advanced countries. In addition, developing countries caught in the “knowledge trap” will have the opportunity to specialize, and gain from trade, reducing the range of capabilities required to escape that trap.

The globalized R&D networks being created by leading multinationals offer an example of how this international division of labor could work in practice. The latest technological revolutions may be limiting the ability of traditional channels of technology diffusion to continue to operate as they have in the past. But the same revolutions are opening up new opportunities for technology diffusion. Ensuring that these opportunities are fully realized will require a revitalized WTO, capable of coordinating policy in a digital age of expanding data flows. To be effective in this role, the WTO itself will need to become more knowledgeable of these emerging technologies and international trade opportunities. We see this volume is a step in this direction. For all of us, much remains to be done.

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2. Recognizing the challenges that the modern world presents to economic theory, Elhanan Helpman titled his thoughtful 2004 book, *The Mystery of Economic Growth*. [↑](#footnote-ref-2)
3. Many of the chapters in this volume analyze such data and their shortcomings. [↑](#footnote-ref-3)
4. This growth is documented in the OECD’s online trade in value added (TIVA) database, at http://www.oecd.org/sti/ind/measuring-trade-in-value-added.htm. [↑](#footnote-ref-4)
5. In this literature the innovation response of Southern firms to stronger IPRs is usually absent. A notable exception is He and Maskus (2012), who present a model in which FDI may result in “reverse” spillovers from South to North. The general absence from these models of induced Southern innovation reflects, in part, the lack of unambiguous evidence to date that stronger IPRs stimulates a significant rise in domestic innovation (Lerner, 2002). [↑](#footnote-ref-5)
6. The emergence of the Republic of Korea and Chinese Taipei as innovating economies in the 1990s coincided with the arrival of these economies to income levels equaling those of the poorer European OECD member states and a degree of human capital accumulation that exceeded nearly all of them. In other words, by the time they had emerged as important innovators, the Republic of Korea and Chinese Taipei were no longer developing countries. [↑](#footnote-ref-6)
7. National Science Foundation, National Center for Science and Engineering Statistics, *Survey of Earned Doctorates.* [↑](#footnote-ref-7)
8. See Freeman and Huang (2015) for an overview of China’s massive mobilization of science and engineering talent. [↑](#footnote-ref-8)
9. According to USCIS Fiscal Year 2016 Annual Report to Congress: “Characteristics of H-1B Specialty Occupation Workers.” [↑](#footnote-ref-9)
10. While trade in services has traditionally been poorly measured, in recent years the Bureau of Economic Analysis has made considerable strides in categorizing and measuring U.S. international transactions in disaggregated services, including in the areas of producer, business, and IT services. [↑](#footnote-ref-10)
11. The potential welfare costs of data protection are not yet well understood and just now becoming the subject of extensive analysis. An early entrant (Bauer, et al., 2014) finds, in a CGE framework, that recently implemented and newly proposed restrictions, including economy-wide requirements for data localization, in several countries (including China and the EU) could generate substantial losses in domestic investment and real GDP. Losses of that type would surely mount if such restrictions became globally common as AI and related services take on premier roles in sharing knowledge. [↑](#footnote-ref-11)
12. This section borrows heavily from Muradliharan et al. (2018). [↑](#footnote-ref-12)
13. One could also imagine AI algorithms streamlining the innovation process itself, amplifying human cognitive effort in the same way that three hundred years of industrial progress have amplified human physical effort. [↑](#footnote-ref-13)