

## Technological change

### Key findings

- **Trade costs are likely to continue to fall.** New digital technologies enhance opportunities for global value chain (GVC) participation. Developing countries, which exhibit the highest costs and biggest impediments to trade, stand to gain the most.
- **Platform firms and e-commerce generate uneven benefits across firms and households.** Platform firms facilitate participation but also foster concentration, which affects the distribution of gains from participation in GVCs.
- **Anxiety that automation will hinder export-led industrialization may not be warranted.** Evidence of reshoring is limited. New production technologies have promoted North-South trade, although the effects are heterogeneous across countries and sectors.
- **Increased automation in manufacturing is likely to have distributional impacts.** Adoption of robots is driving down the labor share of income and increasing the demand for skilled workers, thereby exacerbating inequality in the labor market and increasing the need for adjustment policies to support disrupted workers.
- **Restricting trade to promote manufacturing is counterproductive.** It lowers efficiency, raises prices of both inputs and outputs, and undermines incentives to innovate.

Supply chains are rapidly changing under the pressure of digital innovation. Robotics, 3D printing, big data, blockchain technologies, cloud computing, the Internet of Things, and the rise of platform firms are transforming production and distribution processes in many industries. Digital technologies raise productivity but are also disruptive, especially when they lead to a reduction in demand for workers. Meanwhile, a substantial share of exports from low-wage developing countries is in sectors being rapidly automated by their trade partners. These developments have sparked fears that industrialization led by labor-intensive exports may no longer be a viable model for developing economies seeking to develop by joining and then moving up the value chain—and that labor costs are becoming a less important determinant of competitiveness. Moreover, changing skills demands associated with technological progress could place developing countries at a disadvantage.

This chapter reviews the evidence on how emerging digital technologies, including advanced robotics and 3D printing, are affecting global value chains (GVCs), trade flows, and the prospects for export-led industrialization. In doing so, it reviews the channels through which technological progress could have impacts on GVCs—reducing trade costs, inducing quality upgrading and product churning, and changing productivity and relative costs across countries and sectors, thereby changing comparative advantage. It then explores how changes in trade policy might alter these effects<sup>1</sup> and offers a tentative assessment of the potential for continued expansion of global supply chains and export-led development. New technologies will likely change GVCs and the trade and jobs they create. But forecasting exactly how is fraught with uncertainty, not least because technological progress is difficult to predict.

Trade costs are likely to continue to fall because of new digital technologies, offering greater opportunities for GVC participation. Developing countries may stand to gain the most from emerging digital technologies because they face the highest trade costs and biggest distortions. Extending access to high-speed Internet and expanding e-commerce will facilitate greater GVC participation. But the gains from e-commerce are unevenly distributed across households, and not all firms benefit equally from Internet access. Artificial intelligence applications, such as machine translation, can further reduce trade and logistics costs, and might also help reduce red tape. Platform firms make it easier to participate in global markets. But the reputation mechanisms they rely on

to verify seller and buyer quality may foster concentration, which makes it harder for entrants to compete. Platform firms also pose new challenges for regulators seeking to ensure fair competition and prevent abuse of market power. Meanwhile, because of technological progress more goods and services, as well as new ones, are likely to become tradable over time.

Anxiety that automation will hinder export-led industrialization may not be warranted. Evidence of companies moving operations back to their home country (reshoring) is very limited, and new production technologies such as industrial robots and 3D printing have promoted North–South trade, although the effects are heterogeneous across countries and sectors. Those that mainly compete with robot-adopting countries in output markets are at risk of being outcompeted by foreign robots and may suffer substantial reductions in employment. Adoption of robots is driving down the share of income accruing to labor and increasing the demand for skilled workers that perform tasks that complement those performed by robots, thereby exacerbating inequality.

Robot adoption improves productivity, which leads to an expansion in output and increased demand for material inputs. It also leads to the creation of new tasks. In spite of these benefits, robot adoption will likely entail substantial labor market pain.

Increasing tariffs to shield domestic industries from intensified competition associated with the adoption of new production technologies in other countries is likely counterproductive because it lowers efficiency, raises the prices of both inputs and outputs, and undermines incentives to innovate.

## Declining trade costs

### The Internet facilitates GVC participation

The information and communication technology (ICT) revolution that emerged in the mid-1990s has been an important enabler of the expansion of GVCs. The share of the global population using the Internet grew from less than 1 percent in 1993 to 46 percent in 2016. By 2014, almost all firms (with at least five employees) in high-income Organisation for Economic Co-operation and Development (OECD) countries used a broadband Internet connection. Among firms in lower-income countries, broadband usage remains lower, but it is rising rapidly.<sup>2</sup> At the same time, the cost at which information can be transmitted via an optical network has fallen dramatically. In fact, today the time it takes to download a high-definition movie through a modem connected to fiber optics is

almost imperceptible. This ICT revolution has not only reduced trade costs by lowering the cost of processing and transmitting information over long distances, but it also has enabled firms to improve productivity and has led to a new range of information technology (IT)-related services. These advances have contributed to a rise in global trade and production sharing because firms are increasingly spreading their production process across borders and sourcing more intermediate inputs and services from abroad.<sup>3</sup>

High-speed Internet enables firms in developing countries to link to GVCs. The introduction of fast Internet in Africa and China has spurred employment and export growth, as recent studies of the economic effects of the rollout have shown.<sup>4</sup> In Africa, the gradual arrival of submarine Internet cables led to faster job growth (including for low-skilled workers) in locations that benefited from better access to fast Internet relative to those that did not, with little or no job displacement across space. Increased firm entry, productivity, and exporting are among the drivers of the higher net job creation in these locations. Similarly, in China provinces experiencing an increase in the number of Internet users per capita also witnessed faster export growth, with more firms competing in international markets and a higher share of provincial output sold abroad.<sup>5</sup> These examples attest to the potential of ICTs to help countries become part of international supply chains. They also show that the uneven provision of ICT infrastructure can aggravate spatial inequalities if already productive regions are the prime beneficiaries of infrastructure upgrading.

### **Digital technologies are lowering logistics and coordination costs**

Digital technologies can improve customs performance by automating document processing and making it possible to create a single window for streamlining the administrative procedures for international trade transactions. In Costa Rica, a one-stop online customs system increased both exports and imports.<sup>6</sup> Similarly, in Colombia computerizing import procedures increased imports, reduced corruption cases, bolstered tariff revenues, and accelerated the growth of firms most exposed to the new procedures.<sup>7</sup>

Digital technologies also facilitate trade in existing services and may promote new services (such as videoconferencing and telecommuting) supporting GVCs. The services trade is becoming more important, and the World Trade Organization projects it will rise from approximately 21 percent of world trade today to 25 percent by 2030.<sup>8</sup>

Meanwhile, cloud computing offers a pay-as-you-go subscription model for storage and software, facilitating file sharing between cross-country teams and lowering the fixed costs of investments in IT infrastructure.

Some robotics and artificial intelligence applications might further reduce logistics costs, the time to transport, and the uncertainty of delivery times (box 6.1). At ports, autonomous vehicles might unload, stack, and reload containers faster and with fewer errors. Blockchain shipping solutions may lower transit times and speed up payments. The Internet of Things has the potential to increase the efficiency of delivery services by tracking shipments in real time, while improved and expanded navigation systems may help route trucks based on current road and traffic conditions. Although the empirical evidence on these impacts is limited, it is estimated that new logistics technologies could reduce shipping and customs processing times by 16 to 28 percent.<sup>9</sup>

### **Investments in digital technologies may be especially beneficial for developing countries**

Ongoing technological progress, more widespread adoption of existing digital technologies, and investments in transport infrastructure are likely to reduce trade costs, promote trade, and lead to a continued expansion of GVCs. These developments may especially benefit developing countries, which currently face higher trade and transport costs and have comparatively limited ICT infrastructure. For example, 4G network coverage remains low in large parts of Africa compared with that in richer countries (map 6.1). Tariffs and nontariff measures continue to pose a significant restriction to trade by low-income countries, despite preferential access programs.<sup>10</sup> In addition, developing countries face large intranational trade costs, which determine the extent to which producers and consumers in remote locations are affected by changes in trade policy and international prices. For example, the effect of distance on trade costs within Ethiopia or Nigeria is four to five times larger than in the United States. Intermediaries capture most of the surplus from falling world prices, especially in more distant locations. Therefore, consumers in remote locations see only a small part of the gains from falling international trade barriers.<sup>11</sup> Despite recent advances in the provision of ICT infrastructure, the scope for further expanding access to high-speed Internet in developing countries remains huge.

In part because of high trade costs, firms in low-income countries tend to operate on a small scale and

## Box 6.1 Digital innovation and agricultural trade

Distributed ledger technologies (DLTs) are decentralized systems for recording transactions of assets in which the transactions and their details are recorded in multiple places at the same time. DLTs could increase efficiency and transparency in agricultural supply chains by improving product traceability and integrity, contract certainty, verification of geographic origin, and compliance with sanitary and phytosanitary requirements. They could also improve the implementation and monitoring of provisions of World Trade Organization agreements relevant to the agricultural trade. DLTs can ensure that gains from trade accrue more directly to producers and consumers.<sup>a</sup> Meanwhile, the food losses in food systems could be reduced by up to 30 million tons a year if blockchains monitored information in half the world's supply chains.<sup>b</sup>

Blockchain technology is still in its infancy, but pilots testing its use are rapidly spreading. One of the most successful initiatives is the Food Trust consortium run by IBM. It uses blockchain technologies to improve the traceability of food, and it has brought together large retail and food industry companies from across the world, including Dole, Driscoll's, Golden State Foods, Kroger, and McCormick. As part of this consortium, Carrefour, a supermarket chain in France, uses blockchain technology to provide consumers

with detailed information on purchased chicken, such as veterinary treatments, freshness, and other metrics.<sup>c</sup> Similarly, Barilla, an Italian pasta and pesto sauce manufacturer, uses blockchain technology to improve transparency and traceability in its pesto production cycle along the entire supply chain—from farm to fork.

Meanwhile, many start-ups are aiming to shorten agriculture value chains and reduce the role of intermediaries. INS, an e-commerce platform, uses DLTs to directly connect producers and consumers through data integration. And AgriDigital, an Australian company, uses blockchain-enabled contracts to facilitate interactions among the various players in the grain supply chain.

To ensure their scalability and accessibility, DLT solutions require the appropriate ecosystems. Although some elements of such ecosystems are technology-specific, they also largely rely on enabling policy, regulatory, and institutional conditions, as well as basic requirements for infrastructure, literacy (including digital), and network coverage.<sup>d</sup> As one example, according to a recent PricewaterhouseCoopers survey,<sup>e</sup> regulatory uncertainty around blockchain-based solutions was identified as a major scale-up challenge across various sectors. Other major challenges are interoperability and the potential failure of different blocks within the chain to work together.

a. Jouanjean (2019).

b. WEF (2018).

c. OECD (2019).

d. Tripoli and Schmidhuber (2018).

e. PwC (2018).

are less likely to export or import. A typical modal manufacturing firm in the United States has 45 workers, and larger firms tend to be more productive and pay higher wages and are more likely to export and import.<sup>12</sup> By contrast, a modal firm in most developing countries has one worker, the owner. Among firms that do hire additional workers, most hire fewer than 10. In India, Indonesia, and Nigeria, firms with fewer than 10 workers account for more than 99 percent of the total.

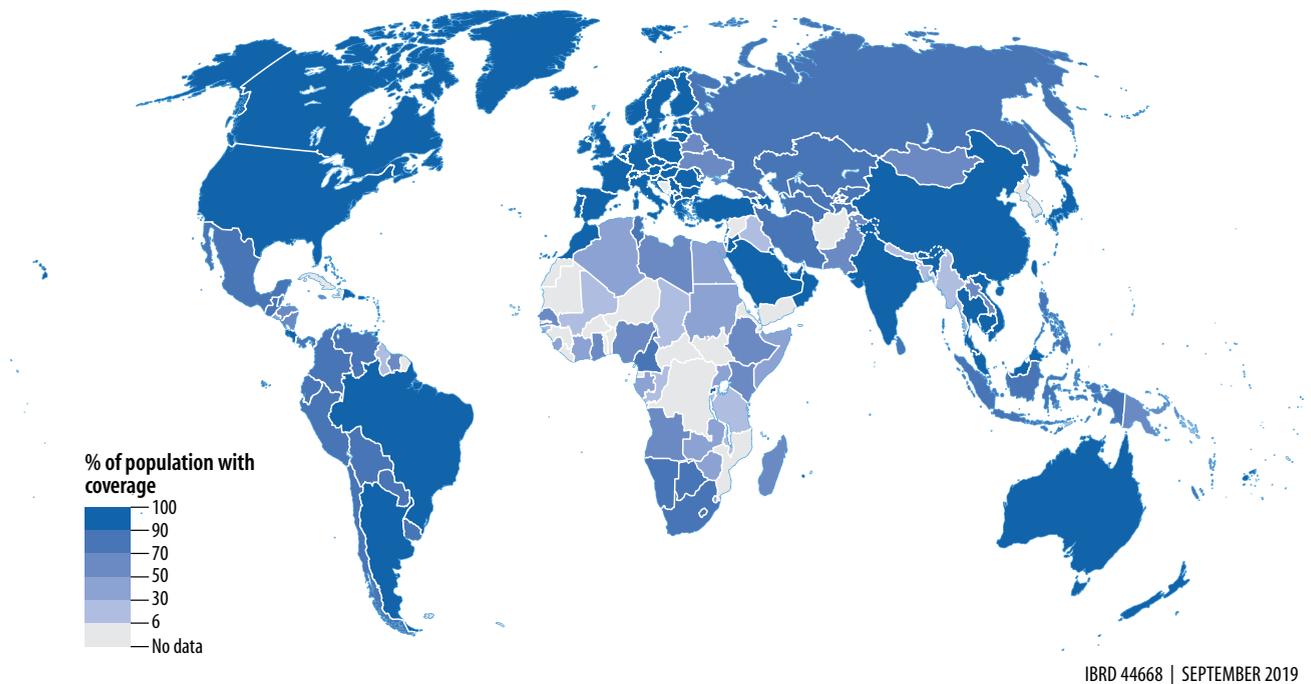
Developing countries tend to have a smaller number of exporters and a lower concentration of export revenue in their top exporters, suggesting that these firms face greater distortions.<sup>13</sup> Investments in reducing barriers to competition and minimizing frictions may thus be especially beneficial for developing countries.

### Digital marketplaces are on the rise, fostering GVC participation—and concentration

Greater access to (and more extensive use of) broadband Internet and digital-enabled devices would also connect more consumers and firms in low-income countries to online markets and business-to-business platforms.

Digital marketplaces and online retailers are on the rise. Platforms such as Alibaba, Amazon, eBay, Taobao, and Mercado Libre are becoming an increasingly important interface between global manufacturers and consumers. At the same time, manufacturers and traditional retailers are seeking to achieve a stronger online presence, alongside their standard distribution channels. Consumers worldwide purchased approximately \$2.86 trillion in goods and services online in

Map 6.1 4G network coverage, 2018



IBRD 44668 | SEPTEMBER 2019

Source: GSMA Intelligence (<https://www.gsmainelligence.com>).

2018, up from \$2.43 trillion in 2017. The share of online sales in total retail sales increased from 11.3 percent in 2016 to 13.3 percent in 2017.<sup>14</sup>

E-commerce is growing especially rapidly in China. The United States and China—the world’s two largest economies—accounted for more than half of global e-commerce sales in 2017. China is the largest e-commerce market, with sales of \$877 billion in 2017, up 28 percent from 2016.<sup>15</sup> In China, the share of online sales in total retail sales reached 15 percent in 2017, up from 12.6 percent in 2016. In the United States, consumers spent \$449.88 billion on retail sites in 2017, up 15.6 percent from 2016; online penetration reached about 13 percent of total retail sales.<sup>16</sup> E-commerce sales are likely to continue to rise in developing countries as Internet access and usage expand. Improvements in enabling infrastructure, such as e-payment systems, logistics, third-party authenticators, and dispute resolution support services can further augment e-commerce.

Platform firms have emerged as the largest companies in the world, but geographically they are not distributed evenly. Seven of the 10 largest global companies by market capitalization in the first quarter of 2019 were platform firms, up from only three in 2015 and two in 2011 (table 6.1). These platform firms

are predominantly from North America and East Asia; Africa and Latin America are greatly under-represented. The role of first-mover advantages in the establishment of platform firms may make it difficult for Africa, Latin America, and even Europe to bridge the gap.

A limited number of e-commerce platforms dominate most markets (figure 6.1). Amazon ranks first by traffic share in North America, Western Europe, and parts of the Middle East and India; Alibaba is the most visited site in China and some parts of the Middle East; and Mercado Libre tops Latin America (map 6.2). The activities of platform firms are thus highly concentrated among a few large megafirms.

Platforms enable GVC participation (box 6.2), but they may lead to concentration because their business model relies on building and exploiting network effects. They reduce transaction costs and help verify the quality and reputation of suppliers and match them to potential foreign buyers.<sup>17</sup> One study finds that the extent to which distance reduces trade is 65 percent smaller for eBay than for total trade flows (for the same set of goods and countries).<sup>18</sup> Although platform firms offer opportunities for new actors to connect and integrate into GVCs, the mechanisms that they typically use to overcome information

**Table 6.1** Ten largest global companies, by market capitalization, 2011, 2015, and 2019

Year	Ranking	Company	Country	Market value (US\$, billions)
2019	1	<b>Apple</b>	United States	961.3
	2	<b>Microsoft</b>	United States	946.5
	3	<b>Amazon</b>	United States	916.1
	4	<b>Alphabet</b>	United States	863.2
	5	Berkshire Hathaway	United States	516.4
	6	<b>Facebook</b>	United States	512.0
	7	<b>Alibaba</b>	China	480.8
	8	<b>Tencent Holdings</b>	China	472.1
	9	JPMorgan Chase	United States	368.5
	10	Johnson & Johnson	United States	366.2
2015	1	<b>Apple</b>	United States	724.8
	2	ExxonMobil	United States	356.5
	3	Berkshire Hathaway	United States	356.5
	4	<b>Google</b>	United States	345.8
	5	<b>Microsoft</b>	United States	333.5
	6	PetroChina	China	329.7
	7	Wells Fargo	United States	279.9
	8	Johnson & Johnson	United States	279.7
	9	Industrial and Commercial Bank of China	China	275.4
	10	Novartis	Switzerland	267.9
2011	1	ExxonMobil	United States	417.2
	2	PetroChina	China	326.2
	3	<b>Apple</b>	United States	321.1
	4	Industrial and Commercial Bank of China	China	251.1
	5	Petrobras	Brazil	247.4
	6	BHP Billiton	Australia/United Kingdom	247.1
	7	China Construction Bank	China	232.6
	8	Royal Dutch Shell	United Kingdom	228.1
	9	Chevron	United States	215.8
	10	<b>Microsoft</b>	United States	213.3

Sources: *Financial Times* Top 500 Companies (<https://www.ft.com/ft500>); *Forbes* Global 2000: The 2019 World's Largest Public Companies (<https://www.forbes.com/global2000/>).

Note: The table lists the top 10 global companies by market capitalization for 2011, 2015, and 2019. Over time, platform firms (shown in bold) have become progressively more important.

frictions, such as consumer ratings that help firms establish a credible reputation, tend to favor concentration. Although platforms enable small and medium enterprises to penetrate export markets, they also make their reputations more widely visible, favoring the emergence of superstar exporters.<sup>19</sup> They make it easier, then, to connect, but harder to compete.

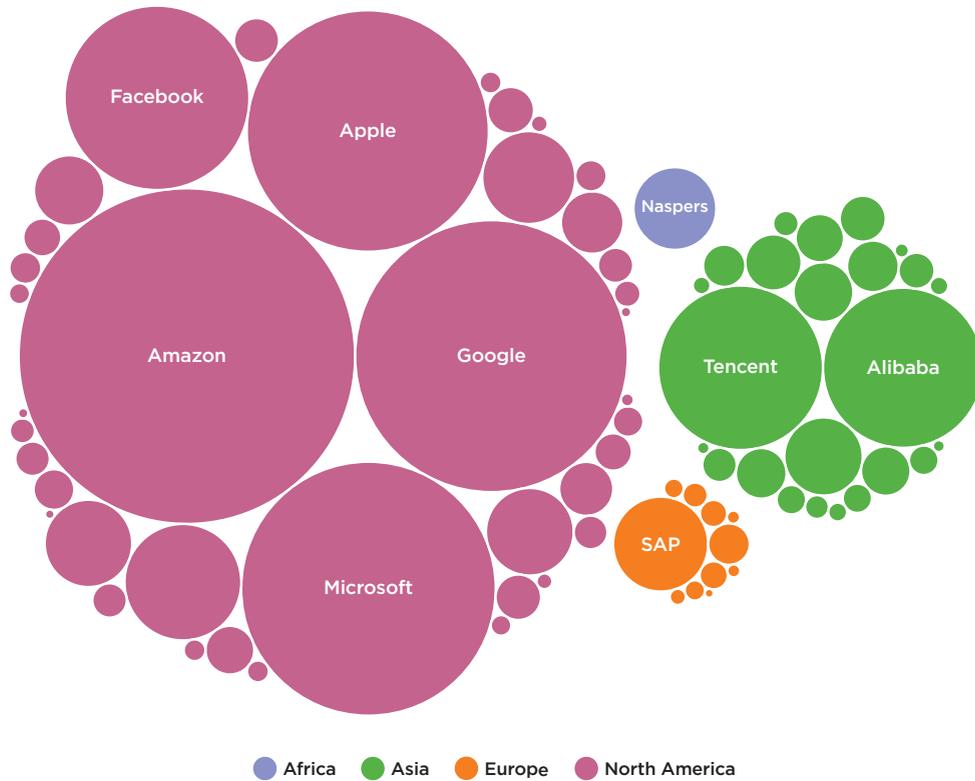
### Artificial intelligence applications are facilitating e-commerce

GVCs and e-commerce may be further supported by recent advances in machine learning. The current generation of artificial intelligence represents a

revolution in prediction capabilities, with potentially broad implications for transaction costs both within and across countries. Enabling this transformation are the greater availability of data, significantly improved algorithms, and substantially more powerful computer hardware.<sup>20</sup> Large firms, multinational enterprises, and big online retailers such as Alibaba and Amazon are increasingly relying on big data and machine learning to understand and forecast consumer behavior and manage their supply chain more efficiently.<sup>21</sup>

Machine learning also reduces the linguistic barriers to trade and GVC participation. One application

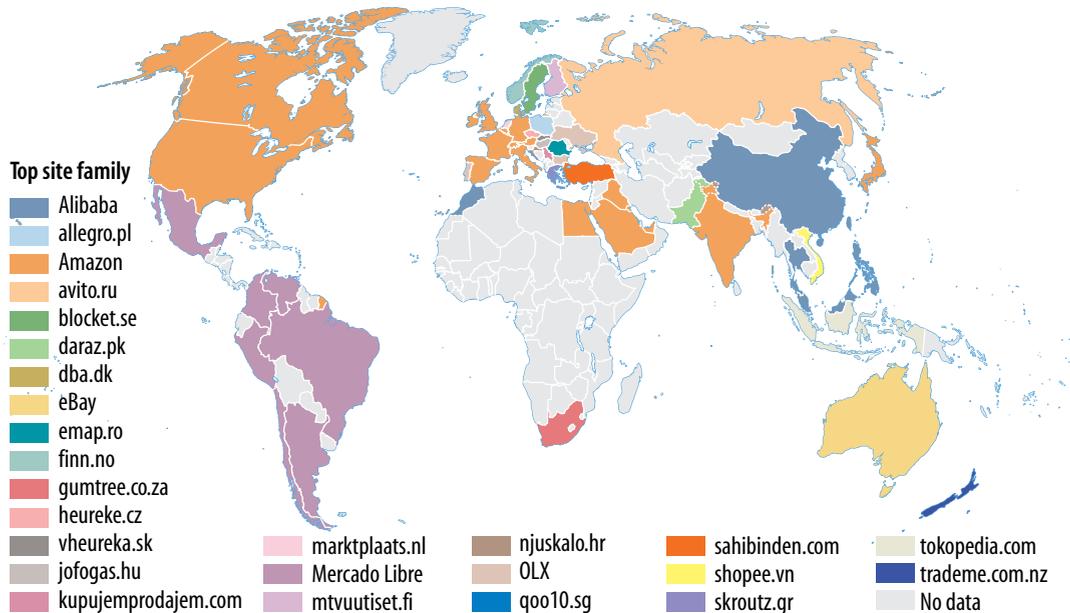
**Figure 6.1** Large platform companies are concentrated in North America and Asia



Source: Peter C. Evans, Global Platform Database, Platform Strategy Institute, 2019.

Note: The figure shows the concentration of the world's 75 largest platform firms by region, with bigger circles representing firms with more market capitalization.

**Map 6.2** Top e-commerce platforms, by traffic share, 2019



IBRD 44667 | SEPTEMBER 2019

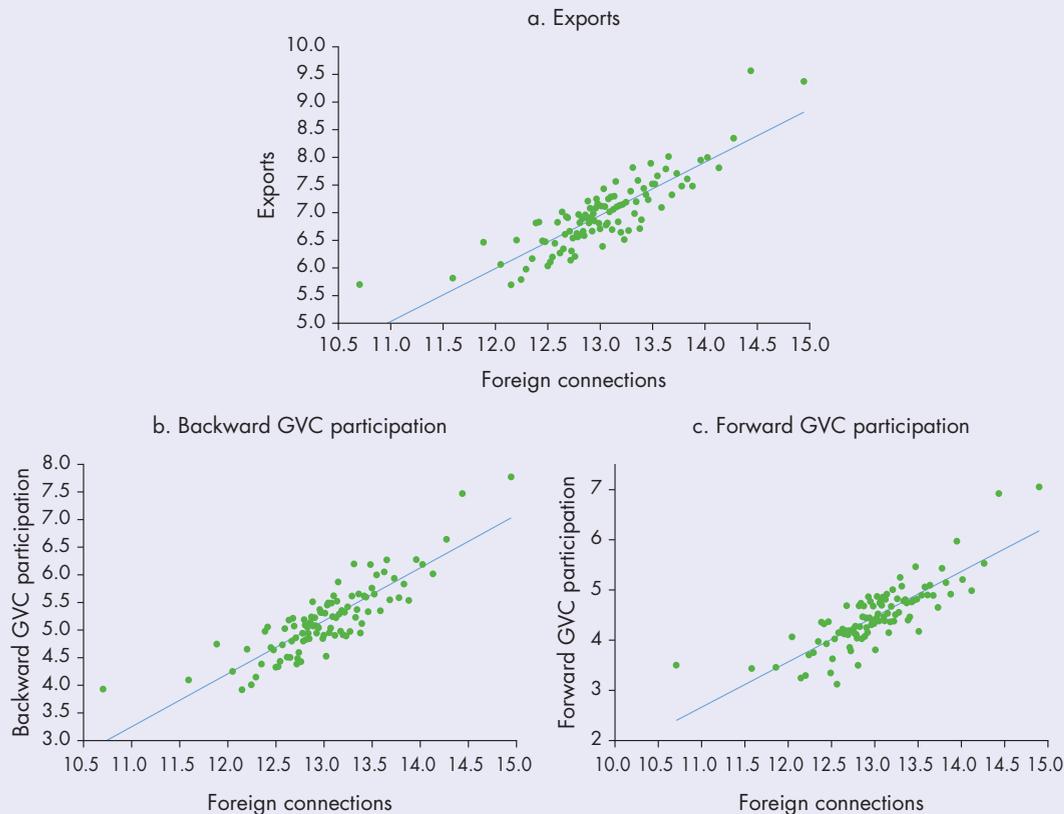
Source: Alexa, SimilarWeb (<https://www.similarweb.com/website/alexa.com#overview>).

## Box 6.2 GVC linkages and cross-border connections between people move together

To operate effectively, GVCs rely on efficient processing of information. This is the point at which platform firms enter the picture because they enable other firms to connect and communicate as well as encourage the formation of new linkages. Professional networks enable the operation of GVCs. To explore the linkages between networks and trade, the World Bank has partnered with LinkedIn, a professional platform with more than 630 million members in over 200 countries and territories. Members of LinkedIn, who provide information on their

educational and career backgrounds, are part of a network and thereby “linked” to other professionals in other firms, sectors, and countries. Analysis of the LinkedIn data (figure B6.2.1) reveals that exports (panel a) and both backward and forward GVC participation (panels b and c, respectively) are strongly correlated with the number of foreign connections indicated by members of LinkedIn. Although causality is more difficult to establish, these patterns suggest that professional networks are complementary to the expansion of GVCs.

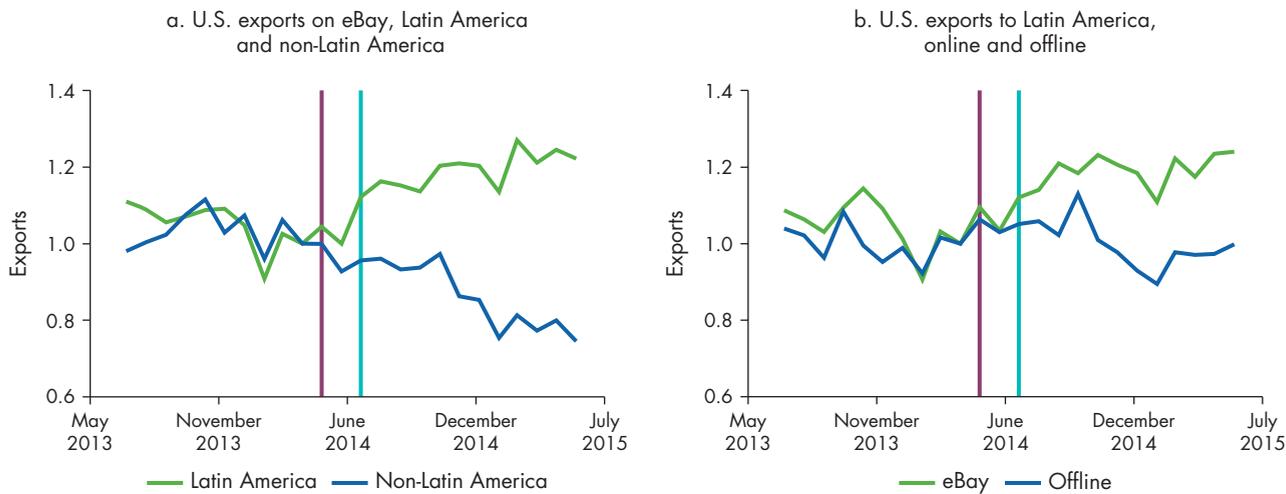
**Figure B6.2.1 Relationship of exports and GVC participation to online foreign connections**



Sources: World Bank Group–LinkedIn Digital Data for Development, Jobs, Skills, and Migration; OECD’s TiVA database. See appendix A for a description of the databases used in this Report.

Note: The graphs show the correlation between the three GVC measures and the foreign connections of members of LinkedIn. The y-axis is based on data from the TiVA data set of the Organisation for Economic Co-operation and Development (OECD) at the sector level (36 sectors) for 64 countries. The variables are the natural log of total exports in millions of U.S. dollars (panel a) and backward and forward participation in GVCs (panels b and c, respectively), also measured in logs of millions of U.S. dollars. The x-axis data are from the Economic Graph at LinkedIn (<https://economicgraph.linkedin.com/>), showing the natural log of the total number of foreign connections in a given sector in the same 64 countries for 2015–18. Each point in the scatterplot represents the mean of the y-axis variable in each of the 100 chosen bins of the x-axis data. The diagonal line represents the prediction of the dependent variable, calculated using a linear regression with additional country and sector fixed effects. Therefore, its slope represents the elasticity between the y-axis and x-axis measures.

**Figure 6.2** From 2013 to 2015, U.S. exports to Latin America through eBay increased after the introduction of machine translation



Source: Brynjolfsson, Hui, and Liu 2018.

Note: Exports in panel a are measured in quantity and normalized to the level in April 2013. Exports in panel b are measured in U.S. dollars and normalized to the level in April 2013. The red vertical line marks the introduction of query translation, and the aqua vertical line marks the introduction of item title translation.

of machine learning—machine translation—has improved in recent years. For example, the best score at the Workshop on Machine Translation for English to German rose from 15.7 to 28.3, according to a widely used comparison metric, the BLEU score.<sup>22</sup> The introduction of machine translation from English to Spanish by eBay has significantly boosted international trade between the United States and Latin America on this platform, increasing exports by 17.5 percent (figure 6.2). These effects reflect a reduction in translation-related search costs and show that artificial intelligence has already begun to boost trade in North and South America. The results further suggest that consumers benefit more than sellers because consumers gain both from reduced language frictions and lower prices. Although the evidence refers to online trade, machine translation may also facilitate communication offline—for example, within multinational firms or across trading partners.

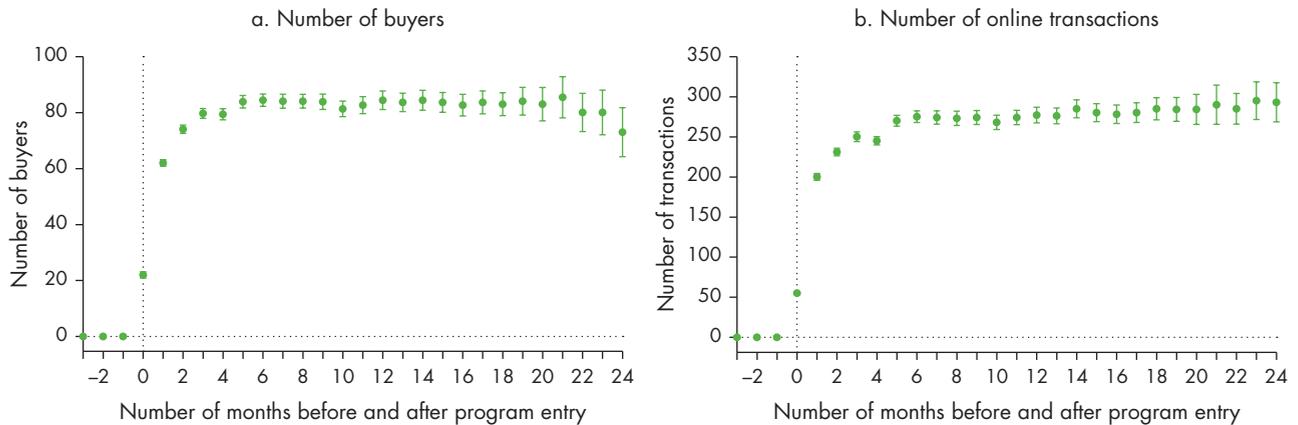
### Platform firms and e-commerce have uneven benefits

Besides fueling GVCs and cross-border trade, deeper integration of e-commerce may also help it reach more firms and households in rural markets in developing countries. In China, the largest e-commerce market, the number of people buying and selling products online grew from essentially zero in 2000 to more than 400 million in 2015. A clear upward trend was

also observed in many other developing countries. Although most of this growth has so far been observed in urban areas, emerging economies such as China, the Arab Republic of Egypt, India, and Vietnam are developing policies aimed at expanding e-commerce to rural areas. But such expansion requires more than Internet access alone. It also means overcoming logistical and transactional barriers, such as the dearth of modern commercial parcel deliveries and rural households' lack of familiarity with how to navigate online platforms and lack of access to (or trust in) online payment services. The sizable welfare gains from e-commerce stem predominantly from reductions in consumer prices and access to new products. In Japan, e-commerce has driven down overall prices, raising aggregate welfare by 1 percent. Meanwhile, new varieties available through online shopping have raised welfare by 0.7 percent, and increased intercity price arbitrage has raised welfare by 0.06 percent.<sup>23</sup>

The gains from e-commerce are unevenly distributed across households. A recent study looked at the effects of a program that invests in the logistics needed to ship products to and sell products from tens of thousands of Chinese villages that were largely unconnected to e-commerce.<sup>24</sup> Between the end of 2014 and middle of 2016, nearly 16,500 villages in 333 counties and 27 provinces in China were connected to e-commerce through the program. The sizable gains from e-commerce trading in both number of

**Figure 6.3** Effects of an e-commerce program on the number of buyers and online transactions in Chinese villages



Source: Couture et al. 2018.

Note: The figure shows point estimates from a regression of depicted outcomes on months since program entry with village and month fixed effects. Outcomes are the number of buyers (panel a) and the number of online transactions (panel b). The data are from a major e-commerce firm's internal database and contain the universe of village purchase transactions from November 2015 to April 2017 in five provinces: Anhui, Guangxi, Guizhou, Henan, and Yunnan (roughly 11,900 villages in total). The last point estimate of each plot pools months 24–28. The graphs show 95 percent confidence intervals based on standard errors that are clustered at the village level. Overall, the figure indicates that the introduction of e-commerce was associated with an increase in both the number of buyers and the number of online transactions.

buyers and number of online transactions (figure 6.3) have, however, tended to accrue to a minority of rural households who are younger, richer, and better positioned to take advantage of the opportunities e-commerce offers. Importantly, the gains have been significantly stronger among villages not previously serviced by commercial parcel delivery, suggesting that the impacts of the program stem mainly from overcoming a logistical barrier rather than from additional investments aimed at adapting e-commerce to transactional barriers specific to rural households.

E-commerce benefits consumers by reducing the cost of living, especially in remote rural areas. On the income side, e-commerce has displacement effects. In the United States, the growth of e-commerce from 3.8 percent of retail sales in 2010 to 8.3 percent in 2017 was associated with a reduction in employment in brick-and-mortar retail stores. In counties with retail fulfillment centers, the labor income of retail workers fell by 2.4 percent after the establishment of such a center, with both younger and older workers experiencing sharper decreases in labor income.<sup>25</sup> Consumption gains thus come at the expense of labor market adjustments.

### Platforms create new regulatory challenges

As platform firms grow, gain access to more private data, and wield market power, so do concerns about anticompetitive behavior. At least for now, however,

the scope for raising consumer prices appears to be fairly limited. Online platforms still account for a fairly small share of the overall retail market. Recent evidence points to strong substitution between online and offline sales for personal computers, news, and advertising.<sup>26</sup> Meanwhile, services such as Google Shopping facilitate price comparisons across online merchants and marketplaces, many of which are still in their infancy.

The interdependencies between platforms' third-party sales for retailers and their own online retail operations can result in potential conflicts of interest and may enable anticompetitive conduct.<sup>27</sup> Hybrid platforms such as Amazon, JD.com, and Flipkart sell their own inventory and also act as an online marketplace for other retailers to sell their products, taking a commission for each order. Operating as both an upstream intermediation market for other firms and a downstream retail market for its final customers may give rise to conflicts of interest. Online shoppers may not be able to tell the difference between a platform's own retail services and its marketplace activities for other merchants. Moreover, hybrid platforms may use the data they collect while operating as a marketplace to identify successful products in the marketplace so that they can then market their own branded version in the same platform.

Another, more traditional, form of potential abuse is predatory pricing, whereby platforms use their privileged access to third-party data to temporarily charge

prices below cost on their own products to gain a permanent competitive edge over other merchants. The concern is not that platforms offer their own products at a lower price than that offered by the original seller, thereby benefiting consumers. It is that hybrid platforms may be able to offer such prices only because of their use of third-party data. They could then adopt temporary pricing strategies to gain more permanent advantages over their competitors and subsequently raise prices. At the same time, it is important to recognize that pricing structures are complex. Subsidies across users can help a platform increase its volume of transactions and benefits. In other words, a platform can charge prices below marginal cost to some participants, which does not necessarily mean that it is engaged in predatory pricing. Alternatively, charging prices above marginal cost to other participants does not necessarily mean market power is at work.

Concerns about anticompetitive behavior are not unique to platform firms. Markups have been rising in many sectors of the economy, and especially so in digital-intensive sectors.<sup>28</sup> The average U.S. markups have risen from 18 percent above marginal cost in the 1980s to the present 67 percent. Similar trends in markups have been documented in other countries. According to OECD, markups have grown more in

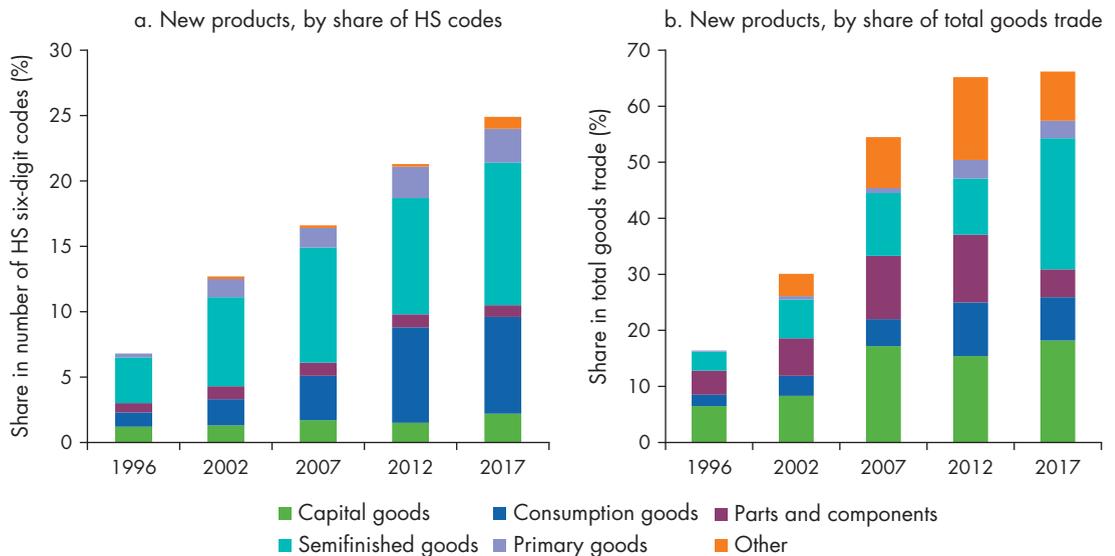
digital-intensive sectors than in others, with the growth driven by firms at the top end of the distribution. These superstar firms are thus accounting for a higher share of profits, which increasingly are unevenly divided.

## New products

Since the 1990s, many new types of products have entered global trade, primarily intermediate goods, further demonstrating the increasing fragmentation of production and the emergence of entirely new products (figure 6.4). Indeed, the trade in new products has grown dramatically. In 2017, 65 percent of trade was in categories that either did not exist in 1992 or were modified to better reflect changes in trade. Trade in intermediate goods (parts and components and semifinished goods) expanded, and entirely new products entered global trade. For example, trade in IT products tripled over the past two decades, as trade in digitizable goods such as CDs, books, and newspapers steadfastly declined from 2.7 percent of the total goods trade in 2000 to 0.8 percent in 2018.<sup>29</sup> Technological developments are likely to continue to produce product churning.

Because of technological progress, more goods and services are likely to become tradable over time. For

**Figure 6.4** Globally, the number and trade share of new products increased from 1996 to 2017



Source: UN Comtrade (International Trade Statistics, Import/Export Data).

Note: Products are classified by a Harmonized System (HS) six-digit code. New products are classified relative to the set of products in the first HS classification in 1988/1992. New codes are either genuinely new products, or old product codes that split into two new codes, or two old codes that merged into one new code. Products are further classified as final (consumption and capital), intermediate (parts and components and semifinished), or primary and other goods using the Broad Economic Categories revision 4 classification from the United Nations Conference on Trade and Development. The figure shows that over time trade in new products has grown dramatically.

example, platforms such as Upwork and Mechanical Turk make it easier for businesses to outsource tasks to workers who can perform them virtually. And new goods and services are likely to be developed, including ones not even imaginable today, thereby boosting the incentives to trade.

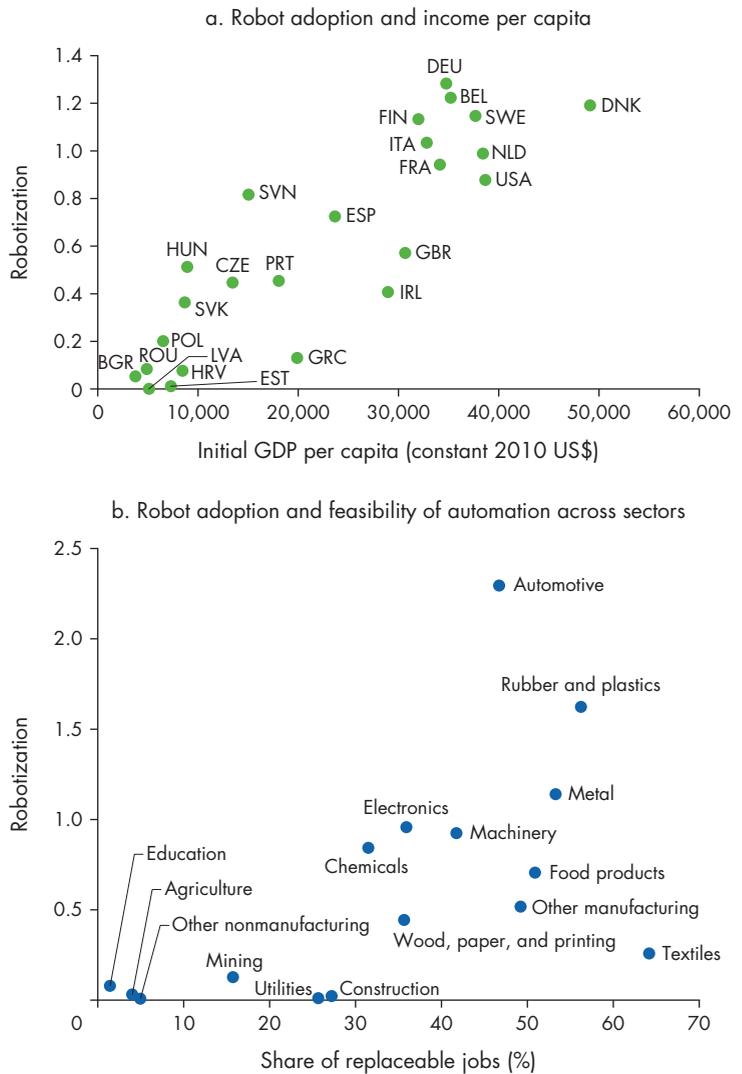
## Automation anxiety

### Robotization is on the rise, raising concerns about the future of GVCs

The spread of new production technologies, such as advanced robotics and 3D printing, has raised concerns about the future of trade and of GVCs. Robotics technology, having advanced greatly in the last two decades, is predicted to develop further in the coming years. The average price of an industrial robot has fallen by half in real terms and even more relative to labor costs. Global sales of industrial robots reached a record 387,000 units in 2017, up 31 percent from 2016. Figure 6.5 shows that robotization is higher in countries with higher income per capita, where wages are higher, and in sectors in which robotization is feasible. Robots are used predominantly in high-wage countries in Asia, North America, and Western Europe (panel a). In recent years, China saw the largest growth in demand for industrial robots and was projected to have the largest operational stock of robots by the end of 2018, but still relatively low robot density.<sup>30</sup> Robotization is most pronounced in the automotive, rubber and plastics, metals, and electronics sectors, reflecting differences in the feasibility of automation (panel b). It is still limited in traditionally labor-intensive sectors such as textiles, suggesting that export-led industrialization in these sectors is still a viable development path. Robot adoption is projected to increase greatly over the coming decade, reflecting further reductions in quality-adjusted robot prices.<sup>31</sup>

Modern industrial robots can be programmed to perform a variety of repetitive tasks with consistent precision, and they are increasingly used in a wide range of industries and applications. If tasks previously performed by low-skilled workers in the South (low-wage developing countries) are performed by relatively inexpensive robots in the North (industrial countries), there may be a reversal in North–South trade flows and a greater reliance on domestic production. Moreover, the skill and capital content of inputs that countries in the North demand from the South may increase now that the North can use robots and other technologies more intensively, as discussed in more depth shortly.<sup>32</sup> The criteria for becoming an attractive production location may

**Figure 6.5 Robot adoption is greater in high-income countries and in sectors in which tasks are easily automated**

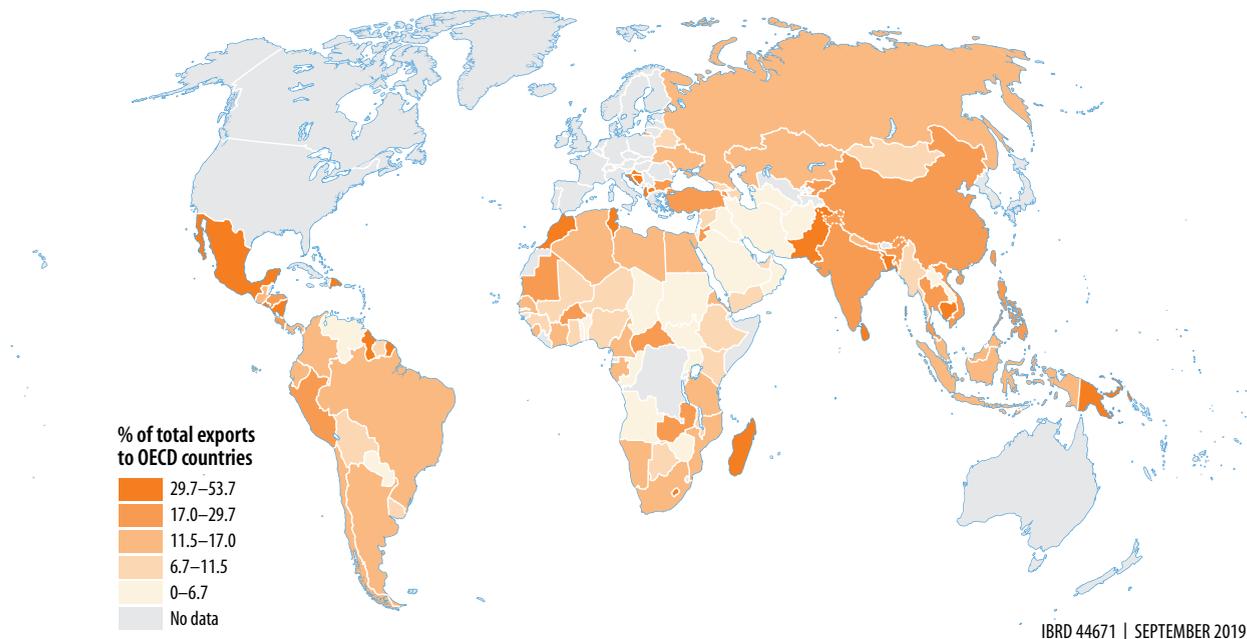


Source: Artuc, Bastos, and Rijkers 2018.

Note: Robotization is the logarithm of 1 plus the ratio of the average stock of robots to the number of working hours (in millions) between 1993 and 2015 (or the subsample of years over this period for which robot data from the International Federation of Robotics [IFR] are available). The stock of robots is estimated using the perpetual inventory method based on the observed stock of robots in the IFR data and using a depreciation rate of 10 percent. The share of jobs that is potentially replaceable by robots is based on the task makeup of the job. See Artuc, Bastos, and Rijkers (2018) for a detailed explanation of how replaceability is measured. For country abbreviations, see International Organization for Standardization (ISO), <https://www.iso.org/obp/ui/#search>.

change as well, with low labor costs becoming a less important determinant of competitiveness (at least in sectors in which automation is feasible), and complementary factors, such as the availability of skills and sound infrastructure, becoming more important.<sup>33</sup> Although the risk of displacement of jobs or exports currently seems low, middle-income countries such

**Map 6.3 A substantial share of exports from developing countries is in goods that can be produced by robots**



Source: WDR 2020 team, based on Artuc, Bastos, and Rijkers (2018).

Note: The map shows exports (by quintile) as a percentage of total exports to high-income OECD (Organisation for Economic Co-operation and Development) countries, weighted by the share of jobs in sectors that produce the exported goods that are potentially replaceable by robots based on their task makeup. See Artuc, Bastos, and Rijkers (2018) for a detailed explanation of how replaceability is measured.

as Mexico, Tunisia, and Pakistan would seem most exposed to the threat of robotization-induced reshoring because their exports are heavily concentrated in goods that robots can help produce (map 6.3). Commodity exporters, however, seem somewhat shielded from the threat of robotization-induced reshoring.

The advent of 3D printing led to predictions that many goods would be printed locally, shortening GVCs and limiting trade. The concern is that if 3D printing becomes cheap, then firms capable of creating a solid 3D object from a digital file will prefer to 3D print products at home rather than import them. 3D printers may therefore perform the tasks previously performed by workers engaged in production and assembly activities located abroad.

These concerns are in part predicated on a few high-profile examples. For example, the sporting goods manufacturer Adidas recently established two “speedfactories” in Germany and the United States that use robots and 3D printing to more quickly produce customizable running shoes for high-income domestic consumers. Adidas hopes the two factories can produce 1 million pairs of shoes a year by 2020, which is still a tiny share of the 403 million pairs it

produced in 2017. Adidas’s competitor Nike has several automated platforms under development.

**Robotization and 3D printing have promoted North–South trade with heterogeneous impacts across countries**

Despite the concerns about the effects of automatization, the evidence that reshoring will result is very limited.<sup>34</sup> Moreover, these technologies may enhance GVCs and boost trade. The spread of automation in richer countries can improve productivity and income, thereby raising the demand for inputs and final goods from countries with large pools of low-wage labor as a comparative advantage. Furthermore, developed countries with similar factor endowments and technologies trade a great deal among themselves. Even if the labor advantage of low-income countries is (partially) canceled out by robotization, there will still be opportunities for trade in differentiated goods and for specialization in some stages of production.

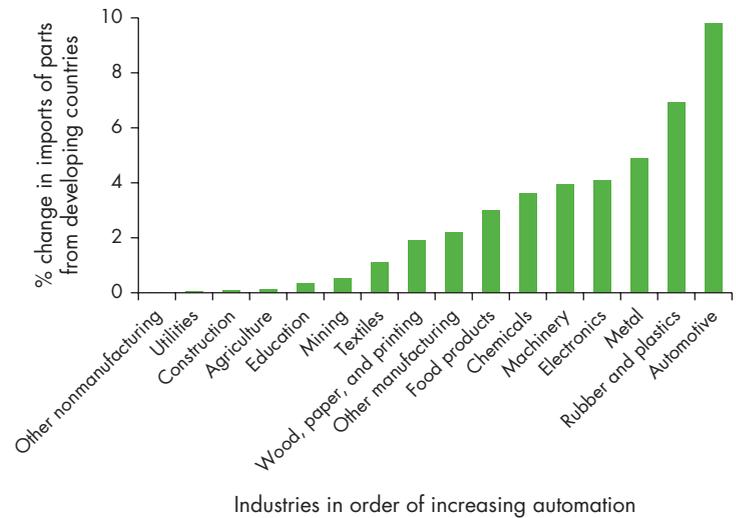
Thus far, the rising adoption of industrial robots and 3D printing seems to have promoted North–South trade. Greater robot intensity in production has led to more imports sourced from lower-income countries

in the same broad industry—and to an even stronger increase in gross exports (which embody imported inputs) to those countries. The surge in imports from the South has been concentrated in intermediate goods such as parts and components. The positive impact of automation on imports, particularly on imports of intermediates, attests to the importance of examining the effects of robotization on trade through a GVC framework. More-traditional trade models would predict the increase in exports by the North but fail to foresee the surge in imports from the South in the same industry.<sup>35</sup> Rather than reducing North–South trade, robotization seems to have been boosting it, although it is uncertain whether this trend is likely to continue.

These average effects mask heterogeneity across countries and sectors (figure 6.6). The biggest automation-induced increase in trade has been in the quick-to-automate automotive sector. Countries already supplying inputs to automating producers in the North are well positioned to benefit from the higher demand for their exports. But countries directly competing with them in output markets could lose export revenue and manufacturing employment if their workers are outcompeted by foreign robots. The negative effects of reduced manufacturing employment could outweigh the welfare gains associated with the lower import prices resulting from automation in the North, at least in the short run. But these countries might benefit from automation-induced increases in global productivity and income, which could translate into more exports and activity in sectors where they retain a comparative advantage.

A related dynamic of innovation-induced trade can be observed in goods that can be produced using 3D printers, such as hearing aids (box 6.3). In 2007 hearing aids shifted almost entirely to 3D printing, and trade increased when compared with similar goods (figure 6.7). Estimates that take into account industry growth and the standard determinants of trade reveal that trade in hearing aids was boosted by 60 percent following the introduction of 3D printing. Other industries producing goods that were partially 3D printed have demonstrated that the technology has similar positive effects on trade. The results are at odds with the view that 3D printing will shorten supply chains and reduce trade, at least for this set of products. The findings do suggest that gains may disproportionately accrue to middle- and high-income countries, and thus they serve as a reminder that the gains from the introduction of new production technologies are likely to be unevenly distributed across countries.

**Figure 6.6 Automation in industrial countries has boosted imports from developing countries**



Source: Artuc, Bastos, and Rijkers 2018.

Note: The figure depicts the automation-induced increase in imports of parts by developed countries (North) from developing countries (South) by broad sector from 1995 to 2015. The change in imports of parts is measured in log points; a 0.10 increase in log points is roughly equivalent to a 10 percent increase in imports.

### Automation is compressing labor’s income share but not necessarily reducing employment

As automation improves productivity, it also compresses labor’s share of income in advanced economies. Higher robot density at the industry level is associated with a lower labor share of income, defined as total labor compensation over sales (figure 6.8). This pattern has implications for inequality because it suggests that the primary beneficiaries of automation are the owners of capital. Moreover, technological progress and the accompanying cost reductions in the relative price of capital goods may be contributing to the global decline in labor’s share of income observed across countries over the past few decades.<sup>36</sup> Although the jury is out on the drivers of this decline, the fall in the labor share across sectors is highest in sectors undergoing concentration and the emergence of superstar firms. These firms make high profits and typically have a lower share of labor in sales and value added, in part because they are harnessing technological innovations.<sup>37</sup>

Robot adoption among OECD countries has reduced the employment share of low-skilled workers in robot-intensive industries. Across local labor markets in Mexico and the United States, workers with a high exposure to domestic robotization have witnessed a reduction in employment and wages relative to those with more limited exposure.<sup>38</sup>

### Box 6.3 Fully automating the production of hearing aids

A common refrain is that automating production, such as with 3D printing, will allow companies to produce goods closer to markets. Companies will drastically shorten their value chains, which will reduce international trade. Lower-income countries will be most affected because their exports are often intermediate products based on abundant, low-cost labor. One attempt to quantify and predict the trade impacts of 3D printing stated it could eliminate as much as 40 percent of trade by 2040.<sup>a</sup> By contrast, new research on the production of, and trade in, hearing aids suggests quite the opposite.

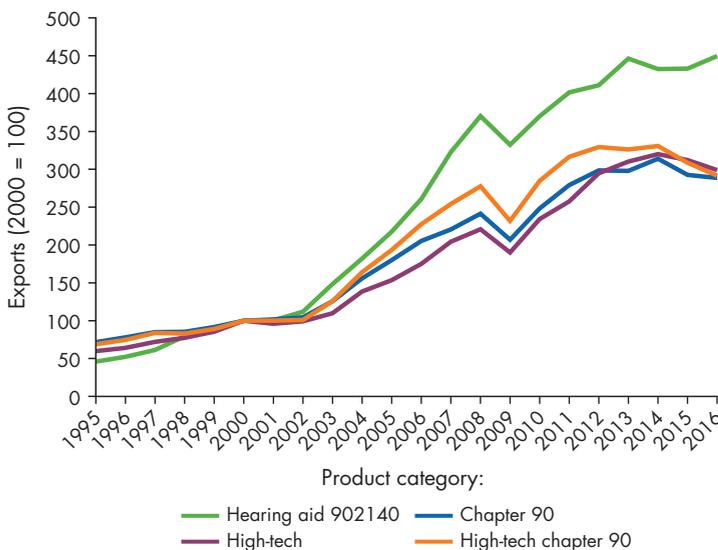
Similar to a standard ink printer, 3D printing uses very little labor and can generate customized products from the same machine. In 2007, following a series of inventions in 3D scanning, software development, and biocompatible materials, the production of hearing aids shifted almost entirely to 3D printing. In the decade that followed, trade increased overall by 60 percent, and because of lower production

costs, prices fell by about 25 percent.<sup>b</sup> Meanwhile, the product underwent improvements: 3D printing allowed for high levels of customization and cosmetic improvements in hearing aids, which reduced discomfort and the stigma for users. Demand increased and trade expanded.

There is no evidence that 3D printing shifted the product closer to consumers or displaced trade—the comparative advantages of different countries in the hearing aid value chain remained the same. Nor does this trend seem to be exclusive to hearing aids. A preliminary analysis of 35 other products<sup>c</sup> that are partially 3D printed found similar positive effects on trade, although to a smaller degree. Perhaps 3D printing had not yet been fully adopted for those products across the entire industry. Unlike the results of the hearing aids analysis, the results of this analysis point to a reshuffling of comparative advantage from labor-abundant countries to countries that adopted 3D printing technologies for each product.

a. Leering (2017).  
 b. Freund, Mulabdic, and Ruta (2018).  
 c. Freund, Mulabdic, and Ruta (2018).

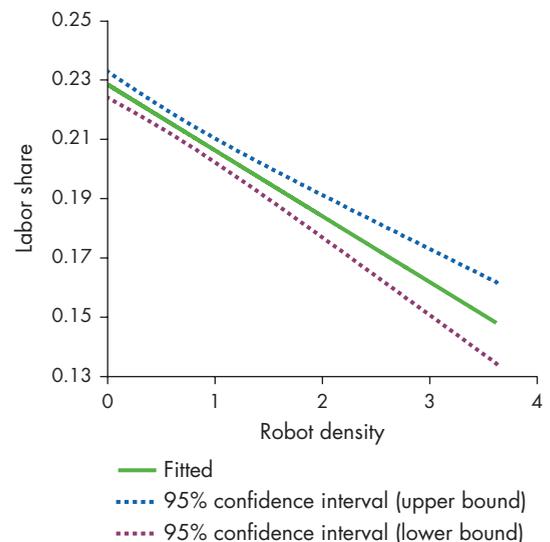
**Figure 6.7 Trade in hearing aids increased with the adoption of 3D printing in 2007**



Source: Freund, Mulabdic, and Ruta 2018.

Note: The Harmonized System (HS) code for hearing aids is 902140. Three additional categories are included for comparison. Chapter 90 covers optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus, and parts and accessories thereof. High-tech are other goods similar to hearing aids found both in and outside chapter 90. High-tech chapter 90 includes high-tech products selected from chapter 90.

**Figure 6.8 Higher robot density is associated with lower shares of income for labor**



Source: Artuc, Bastos, and Rijkers 2018.

Note: The figure shows the association between labor's share of income, defined as total labor compensation over sales, and robot density, defined as the number of robots per million work-hours, for industries in the EU-KLEMS data set for the period 1993–2015.

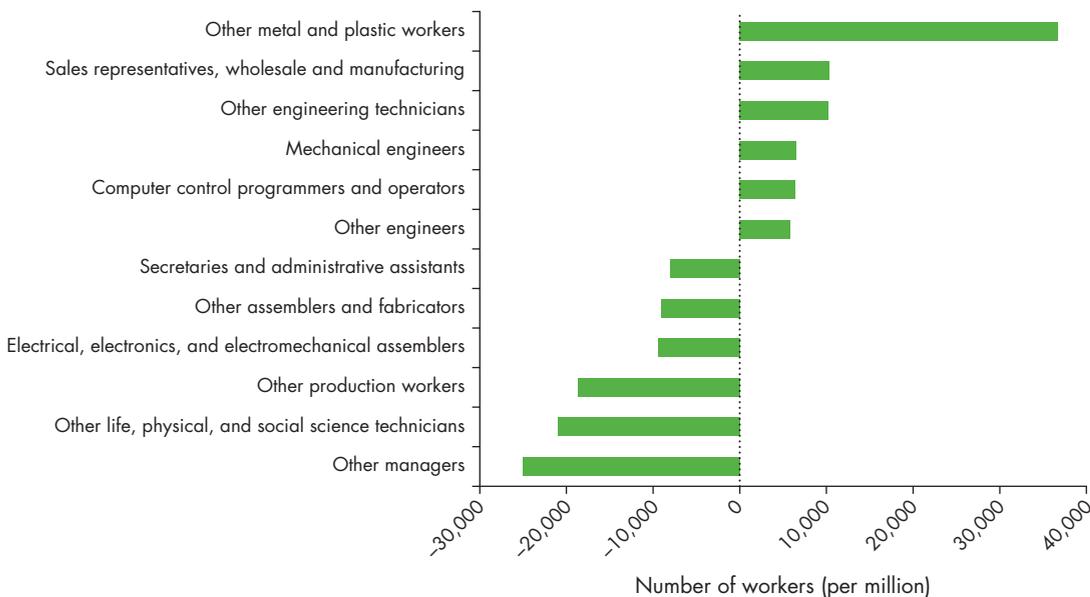
Although automation is no doubt causing pain in the labor market, it would be incorrect to assume that because robots replace workers they always reduce aggregate employment. Robots are a labor-saving form of technological progress and may directly displace jobs, but their adoption can in fact spur job creation through three indirect channels that are challenging to measure. First, the productivity gains in supplier industries can yield steep increases in the demand for labor because of input-output linkages, as shown earlier. Second, productivity growth can boost final demand. And, third, adoption of robots may lead to compositional shifts in the structure of the economy and could create jobs by spurring the growth of sectors with high labor shares. Across member countries of the OECD, industry-level productivity growth has been associated with job losses in the industries in which it originates, but these losses have been more than compensated by indirect gains in customers and supplier industries and growth in final demand. Since the early 1970s, aggregate employment in OECD countries has grown, even though relative employment in industries experiencing the fastest growth in productivity has fallen. Although it is not clear whether

automation ultimately helps or hurts net job creation, it certainly causes significant, and costly, labor market adjustments.

### Automation is changing the demand for skills and comparative advantages

The intuition behind these findings is that automating tasks that can be performed by robots almost surely raises the economic value of the complementary tasks and thus the demand for laborers to perform them.<sup>39</sup> Automation may also lead to the creation of new tasks and products in which human labor has a comparative advantage both at home and abroad. These forces give rise to a *reinstatement effect*, raising the demand for labor by expanding the set of tasks allocated to workers.<sup>40</sup> For example, in industrial sectors where robotization is more prevalent in the United States, low-skilled occupations such as assemblers and production workers experienced sizable job losses over the past decades, while occupations such as sales representatives, engineers, and programmers experienced strong increases in net employment (figure 6.9). Meanwhile, rising incomes due to automation may lead not only to new tasks, but also to new products

**Figure 6.9** Change in U.S. employment in robot-intensive industries, by occupation, 1990–2010



Source: WDR 2020 team, based on tabulations of IPUMS-USA data using the 2010 Harmonized Occupation Classification Scheme.

Note: Data refer to the automotive, machinery, electronics, rubber and plastics, and metal industries. The figure depicts changes in employment for the five occupations with higher and lower net employment creations. The total number of workers in these sectors is normalized to 1 million per year. Occupations labeled as “Other” refer to those not listed separately. Other metal and plastic workers include electrical discharge machine setup operators, metal rivet machine operators, and tin recovery workers. Other engineering technicians include agricultural, biomedical, metallurgical, and optical engineering technicians. Other engineers include optical, ordinance, photonics, and salvage engineers. Other assemblers and fabricators include air bag builders, crate builders, and doll makers. Other production workers include chemical processing machine setters, operators, and tenders; crushing, grinding, polishing, mixing, and lending workers; and cutting workers. Other life, physical, and social science technicians include meteorological aides and polygraph examiners. Other managers include clerks of court, social science managers, and utilities managers.

and services. Greater product customization may require tasks that robots cannot perform.<sup>41</sup> A glance back at the U.S. economy reveals that between 1990 and 2010 the occupational category “retail salesperson” experienced greater net employment gains in the U.S. economy, along with other service occupations such as food preparation (which includes restaurant chefs and sandwich makers). These findings align with those of the *World Development Report 2019: The*

*Changing Nature of Work*, which documents how new technologies are changing the demand for skills and the nature of work.<sup>42</sup>

Future automation in developed and emerging economies will likely affect worker groups differently, and it may exacerbate inequality. Low-skilled workers performing repetitive tasks are more likely to be displaced by robots. In developing countries, however, middle-skill jobs may also be at risk (box 6.4). Women

### Box 6.4 Mexico and technological change

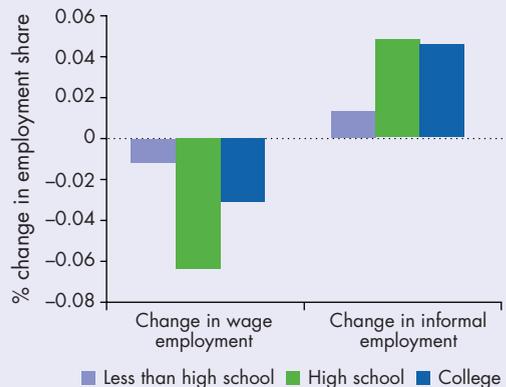
Global value chains link the fates of workers living in different countries because technological progress in one country can affect employment in others.

Over the last two decades, car manufacturers in Detroit have gradually incorporated the use of robots to automate the production of engines, thereby displacing workers. Because some of the engine components are produced elsewhere within GVCs, workers living thousands of miles from Detroit in cities such as Chihuahua, Mexico, where U.S. companies assemble car parts, are exposed to the threat of robotization. In other words, automation in the United States could produce unemployment in Mexico by bringing jobs back to . . . U.S. robots.

But the story is not quite so simple: robots have also increased U.S. productivity, which has led to greater demand for intermediate and consumer products from Mexico and created new jobs for Mexicans (although not necessarily in Chihuahua). For example, roughly 70 percent of the electrical wiring components of U.S. cars are currently produced in Mexico, and their production process cannot be automated. After automation induces a productivity spike, the demand for electrical wiring produced in Mexico could be expected to increase. This productivity boost in the U.S. car industry also increases aggregate income and enhances overall demand. Thus the demand for consumer products, in addition to car parts, from Mexico expands. In the end, it is difficult to predict the size and direction of the impact of high-income country automation on developing country workers operating through international trade channels. Recent evidence indicates that the overall impact of U.S. automation on Mexican workers has been negligible.

Does this mean that Mexican workers have been immune to the negative distributional effects of robotization? No. The use of industrial robots is not limited to high-income countries. In the last 15 years, manufacturers in Mexico have also adopted new automation technologies, but less intensively than manufacturers in the United States. Production technologies in Mexico and the United States are

**Figure B6.4.1 Automation reduces the wage employment of high school graduates**



Source: WDR 2020 team, based on Artuc, Christiaensen, and Winkler (2019).

Note: Figure shows the estimated percentage change in wage employment and informal employment of different skill groups between 2011 and 2016 that can be attributed to local automation in Mexico. The impact is statistically significant for high school graduates, who constitute a larger share of employment in robotized industries, such as automotive, compared with other industries.

linked by large corporations, foreign direct investment, and GVCs. The relationship between domestic and foreign firms as subsidiaries or as arm’s-length suppliers of parts accelerates transfers of technology and eases access to capital in developing countries. And even when different parts are produced by different firms, using similar technologies ensures compatibility.

As producers in Mexico have begun to use industrial robots in the footsteps of their counterparts in the United States, Mexican workers, like U.S. workers, are beginning to be displaced (figure B6.4.1). However, contrary to speculation, the impact has not been through reshoring, but through the diffusion of technological shocks with the global integration of production processes.

also tend to perform more routine tasks than men across all sectors and occupations—tasks most prone to automation. Female workers thus face a higher risk of automation than male workers, with significant heterogeneity across sectors and countries. Less well-educated older female workers are disproportionately exposed to automation, even though the gender pay gap weakens incentives to automate tasks performed by women, who tend to be paid less than men.<sup>43</sup> The potentially dis-equalizing effects of automation are likely to be compounded by the increase in the relative returns to capital that automation is likely to entail, at least in the short run.

This evidence is well aligned with results from model-based counterfactual simulations of the impact of further reductions in robot prices.<sup>44</sup> As robot prices decline, increased automation displaces workers in the North in a wider range of tasks, which initially depresses wages. Welfare nevertheless increases because the income losses associated with lower labor income are more than offset by the higher income from the rental rate of robots and lower consumer prices. The adverse impacts of automation on labor markets may eventually be overturned by further reductions in robot prices. As robot adoption proceeds in the North, production continues to expand and may raise the labor demand for the tasks in which robotization is technologically unfeasible. This situation potentially leads to an increase in the demand for labor and in real wages. Workers in the South may benefit from robotization.

That robot adoption can at times go hand in hand with job creation is illustrated by the U.S. automotive industry, which in recent decades has adopted more robots than any other sector in the United States, both in absolute terms and per worker. From 2010 until 2016, the operational stock of U.S. robots in the automotive sector rose by 52,000 units. At the same time, the number of jobs increased by 260,600, according to the Bureau of Labor Statistics, partly recovering from the steady decline in the previous decade.

## Openness and innovation

How are these patterns affected by trade policy? Inflating trade costs by, for example, imposing tariffs will not only diminish trade, but also influence patterns of technology adoption. Model simulations suggest that developing countries may themselves be *more* likely to adopt labor-saving technologies when trade costs are high. They would then be somewhat shielded from foreign competition in sectors where these technologies are used more intensively as it

would be much more expensive to import goods produced in developed countries using these technologies. But this does not mean that protectionism stimulates innovation. Instead, it likely prevents efficiency-enhancing specialization across countries. By contrast, by opening up opportunities in new markets and fostering competition in domestic markets, trade liberalization tends to incentivize competition and scale and, by implication, innovation. About 7 percent of the increase in knowledge creation during the 1990s was attributable to trade reforms lowering barriers to foreign markets.<sup>45</sup>

Recent firm-level studies point out that international sourcing strategies could serve as a conduit to innovation. For example, evidence from Denmark suggests that offshoring allows firms to devote a larger share of their labor force to innovation-related activities, thereby facilitating technological upgrading. These findings align with evidence from Norway showing research and development (R&D) and international sourcing to be complementary.<sup>46</sup> Cheaper access to imported intermediate inputs raises the returns to R&D. These estimates are also in line with broader cross-country evidence pointing to greater functional specialization in trade: high-income countries tend to specialize in R&D, lower-income countries tend to specialize in fabrication, and specialization in management and marketing is unrelated to income.<sup>47</sup>

Inflating the costs of international sourcing by raising trade protection could thus undermine gains from specialization and stunt productivity growth. Put differently, openness stimulates innovation. The positive impacts of trade openness on technological progress are an often overlooked source of gains from trade.

## Export-led industrialization

Although predicting the future is a treacherous exercise, new technologies will likely reduce trade costs and make it easier to participate in global markets. Such outcomes may offer developing countries new opportunities to link into GVCs. However, the attendant intensification of competition may make it more challenging for countries to succeed. Platform firms, for example, are making it easier to connect, but their reputation mechanisms for verifying supplier quality tend to foster concentration and make it harder for entrants to grow. They are creating new challenges for regulators both because they wield market power and because their interactions with agents in different parts of the value chain may

create potential conflicts of interest and enhance the scope for anticompetitive conduct.

Automation anxiety is not warranted for all developing countries. Although some countries are likely to lose manufacturing employment because of greater competition in output markets, countries that are part of GVCs and supplying inputs to other countries that are automating may see an increase in the demand for their goods, and consumers everywhere will enjoy lower prices. The primary challenge arising from new production technologies is to ensure that the benefits are shared and that losers are compensated both across and within countries. Among the countries adopting these technologies, labor market disruptions are likely to be significant, skill premiums are likely to rise, and labor's share of income may decline further. These outcomes point to the importance of sound social safety nets and redistributive and tax policies to ensure that gains are widely shared without distorting incentives to innovate. These policies will be discussed in chapter 8.

## Notes

1. Artuc, Bastos, and Rijkers (2018); Bown et al. (2017); de la Torre et al. (2015); Dutz (2018); Lopez-Acevedo, Medvedev, and Palmade (2017).
2. In lower-middle-income countries, the share of firms (with at least five employees) using broadband Internet rose from 39 percent in 2006–09 to 68 percent in 2010–14. According to the *World Development Report 2016: Digital Dividends*, the share in low-income countries in 2010–14 was about 38 percent (World Bank 2016).
3. Antràs, Garicano, and Rossi-Hansberg (2008); Costinot, Vogel, and Wang (2013); Fort (2017); Freund and Weinhold (2002, 2004); Grossman and Rossi-Hansberg (2008).
4. See, for example, Hjort and Poulsen (2019).
5. Fernandes et al. (2019).
6. Carballo et al. (2016).
7. Laajaj, Eslava, and Kinda (2019).
8. The McKinsey Global Institute argues that traditional trade statistics do not duly account for the rising importance of trade in services, notably by underestimating (1) the services embodied in goods; (2) the intangibles sent by firms to foreign affiliates; and (3) the proliferation of free digital services made available to global users (MGI 2019).
9. MGI (2019).
10. Hoekman and Nicita (2008).
11. See Atkin and Donaldson (2015).
12. Hsieh and Klenow (2014); Hsieh and Olken (2014); McKenzie (2017).
13. Fernandes, Freund, and Pierola (2016).
14. Young (2019).
15. Young (2019).
16. Young (2019).
17. See Chen and Wu (2018) and Garicano and Kaplan (2001).
18. Lendle et al. (2016).
19. Chen and Wu (2018).
20. Agrawal, Lacetera, and Lyons (2016); Brynjolfsson and McAfee (2017); Mullainathan and Spiess (2017).
21. Columbus (2018).
22. Brynjolfsson, Hui, and Liu (2018), citing <http://matrix.statmt.org/matrix>.
23. Jo, Matsumura, and Weinstein (2019).
24. Couture et al. (2018).
25. Chava et al. (2018).
26. Duch-Brown, Martens, and Mueller-Langer (2017); Gertner and Stillman (2001); Goldfarb and Tucker (2011); Goolsbee (2001); Prince (2007); Seamans and Zhu (2014).
27. Höppner and Westerhoff (2018).
28. Calligaris, Criscuolo, and Marcolin (2018).
29. WTO (2018).
30. IFR (2018).
31. A study by the Boston Consulting Group predicts that growth in installed robotic systems will rise from the current 3 percent annually to around 10 percent annually in the next decade (BCG 2016).
32. See Rodrik (2018) for a detailed discussion of this “technological-compatibility” channel.
33. Hallward-Driemeier and Nayyar (2018).
34. Oldenski (2015) provides evidence that reshoring is not widespread in the United States.
35. Artuc, Bastos, and Rijkers (2018).
36. Karabarbounis and Neiman (2014).
37. Autor et al. (2017).
38. Acemoglu and Restrepo (2018); Artuc, Christiaensen, and Winkler (2019); Graetz and Michaels (2018).
39. World Bank (2019).
40. Acemoglu and Restrepo (2019).
41. For example, in 2016 the car manufacturer Mercedes-Benz decided to replace some of its assembly-line robots with more capable humans at its Sindelfingen plant in Germany. The wide variety of options for the cars demands adaptability and flexibility, two attributes for which humans currently outperform robots. Skilled humans can change a production line in a weekend, whereas weeks are required to reprogram and realign robots.
42. World Bank (2019).
43. Brussevich et al. (2018).
44. Artuc, Bastos, and Rijkers (2018).
45. Coelli, Moxnes, and Ulltveit-Moe (2016).
46. Bøler, Moxnes, and Ulltveit-Moe (2015).
47. Timmer, Miroudot, and de Vries (2019).

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