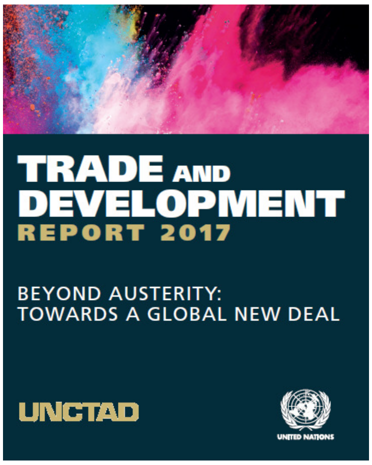
ROBOTS, INDUSTRIALIZATION AND INCLUSIVE GROWTH

Chapter 3



A. Introduction

Employment opportunities, and the income they generate, are a major determinant of inclusive growth. Economists, policymakers and the general public have long accepted that technological change greatly affects employment opportunities. Historically, it has offered novel ways of producing and consuming goods and services, created new profitable areas of economic activity, and underpinned rising living standards. In the process it freed humans from physically demanding, repetitive or dangerous work. However, the creative side of new technologies often has disruptive consequences for the existing practices and structures of economic life, including the outright destruction of companies, markets and jobs, with no guarantee that the gains from the new processes will fully compensate for the losses. Over time, the distributional consequences of new technologies depend on the scope of subsequent job opportunities and the pace at which they materialize. In large part this is because new technologies do not arrive as a *deus ex machina* but are embodied in (and disseminated by) capital equipment, institutional routines and human capabilities, and their impact is, therefore, conditioned by macroeconomic circumstances and policy responses.

Much of the discussion about making hyperglobalization more inclusive emphasizes investment in knowledge and skills as the way to harness human talent to the new opportunities associated with digital technologies (IMF, 2017). In this chapter, it is argued that the issue is more complex and that, in addition to investment in education, the overall framework of macroeconomic and sectoral policies remains crucial to ensuring the expansion of viable employment opportunities at different skill levels.

Economic history certainly suggests that technological breakthroughs, such as the steam engine, electricity, the motor car and the assembly line, have been disruptive and result, in the short run, in substantial job losses and declining incomes for some sectors and sections of society. But it also shows that these adverse effects are more than offset in the long term when the fruits of innovation gradually spread from one sector to another and are eventually harvested across the economy when workers move to new, more technology-intensive and better-paid jobs (Mokyr et al., 2015). However, whether this history offers a useful guide for the effects of digitization is open to question (Galbraith, 2014; Gordon, 2016).

The newest technological wave builds around the generation, processing and dissemination of information. Although the computer launched this new wave, it is advances in the integrated circuit that have given it revolutionary impetus. Subsequent technological developments emerging from sizeable advances in computing power, increasingly sophisticated audiovisual products and artificial intelligence (AI) include the spread of Big Data, the Internet of Things and online sharing platforms. The combination of these different information and communication technologies (ICTs) makes up the digital revolution. Like previous technological revolutions, its impact is felt across most areas of social and economic life, including in employment opportunities. Part of this revolution concerns the potential of new technologies to boost automation and transform production processes. The rapid march of robot technology, in particular, simultaneously captures the imagination of entrepreneurs and policymakers and adds to a deepening sense of anxiety among much of the public.

The goals of the 2030 Agenda for Sustainable Development undoubtedly require harnessing the potential of the digital revolution, such that it accelerates productivity growth and feeds a more rapid and more sustainable global economic expansion. But if productivity growth is achieved on the back of automation that causes job displacement and wage erosion, it would compromise this Agenda, which aims to achieve inclusiveness through the creation of more and better jobs.

Most observers who believe in the transformative potential of digitization acknowledge that productivity growth has faltered in recent years, but argue that most productivity gains associated with digitization lie ahead, that any adverse effects from automation will be short-lived, and that increases in labour incomes and well-being will eventually be widespread (e.g. Brynjolfsson and McAfee, 2014). Seen from the perspective of long-term Schumpeterian waves, the current situation marks the stage of job destruction, related to process innovation, which will be followed by product innovation and ensuing job creation (Nübler, 2016; Perez, 2016). Others are more pessimistic. They hold that the digital revolution is much more disruptive than previous technology waves, because advances in artificial intelligence and robotics increasingly enable the substitution of cognitive, instead of just manual, tasks and this is occurring at an increasingly faster pace. Because of the greater scope of occupational applications of robots and the faster speed of their diffusion, the economy may not have sufficient time to adapt and compensate for job displacement by creating new and better jobs (e.g. Ford, 2015). A plethora of studies and media reports paint an alarming picture of technology destroying more jobs than it creates over time, with some anticipating a jobless future.[1]

Another concern relates to distributional impacts of the "digital storm" (Galbraith, 2014). Many activities that have already become digitized continue to generate an income stream which, as the required employment has dropped precipitously, flows to a small number of people at the top of the digital food chain, often in highly confined geographical regions. On some accounts, the next generation of automated machines will be much more durable and will probably require only a small number of highly skilled workers for their operation, rather than the large numbers of workers at any skill level that complemented earlier technological breakthroughs. As a result, most workers will be unable to move to better-paid jobs by upskilling, but will compete for a shrinking number of similar jobs or move to occupations with lower pay (e.g. Autor, 2015). Hence, the main risk of digitization may not be joblessness, but a future where productivity growth only benefits the owners of robots and the intellectual property embodied in them, as well as a few highly skilled workers whose problem-solving adaptive and creative competencies complement artificial intelligence, while others are forced into precarious employment and "automated inequality".

However, the outcome of technological change is not an autonomous process; it is shaped by economic incentives and policies. The deployment of robots may be seen, at least in some countries, as responding to declining working-age populations. And its labour-saving outcomes have to be seen in the context of the policy turn to austerity and the drive towards lower labour costs that began in the 1980s (*TDR 2010*).

Taking this broader perspective, aggregate employment and income impacts from technology are largely determined by macroeconomic and regulatory forces. Appropriately expansionary macroeconomic policies can mitigate, if not prevent, any adverse employment and income effects from technological advances. However, such policies are currently missing (chapter I of this *Report*). This means that the novelty of the digital revolution lies not only in its greater scope and faster speed alone, but also in its occurrence at a time of subdued macroeconomic dynamism in the developed economies and stalled structural transformation in many developing economies, which tend to hold back the investment needed for the new technology to create new sectors and absorb displaced workers.

A major area of interest has been specifically the greater reliance on robotics in production, with much of the current debate focused on developed countries (e.g. Frey and Osborne, 2013; Acemoglu and Restrepo, 2017), and where the perceived threat to jobs has been heightened by concerns about the offshoring of production activities to developing countries. Obviously, the use of robots is part of a wider process of automation that affects production processes in both developed and developing countries. However, industrial robots differ from conventional capital equipment in that they are (i) automatically controlled (i.e. they operate on their own); (ii) multipurpose (i.e. they are reprogrammable and are capable of doing different kinds of tasks rather than repeating the same task); and (iii) operational on several axes (i.e. they have significant dexterity, as per ISO 8373).[2] These characteristics also make industrial robots different from other forms of automation, such as Computer Numerical Control systems that have allowed for the automation of machine tools since the 1960s but are designed to perform very specific tasks and, even if digitally controlled, lack the flexibility and dexterity of industrial robots. These characteristics and differences have attracted particular attention because of the dramatic changes that they are presumed to bring about, even though more traditional forms of automation, such as the simple mechanization of heavy-duty work, continue to affect production processes over and above those involving robotics. Indeed, this chapter argues that robotization is likely to have a comparatively small effect on such processes in many developing countries, where mechanization continues to be the predominant form of automation.

This chapter takes a development perspective, in which the most important question is whether the greater use of robots reduces the effectiveness of industrialization as a development strategy.[3] This will be the case if robot-based automation makes industrialization more difficult or causes it to yield substantially less manufacturing employment than in the past.[4] The chapter addresses this question within a broader discussion of whether the use of industrial robots can be expected to radically change the types of jobs that will be available in the future, how, where and by whom they will be done, and what impact this would have on possibilities for inclusive growth, in terms of declining income inequality both between and within countries.

Within the field of robotization in general, the main motivation for the focus on industrial robots is that industrialization, as discussed in *TDR 2016*, has traditionally been recognized as the main driver of economic prosperity.[5] It is also related to the emphasis in Goal 9 of the 2030 Agenda for Sustainable Development on the link between technological innovation and industrialization on the one hand and industrialization and sustainable development on the other.[6]

This chapter is organized as follows. Section B discusses the task-based approach to automation. It argues that robots affect industrialization particularly through the displacement of routine tasks that are more prevalent in manufacturing than in agriculture or services. It also argues that displacement by robots is economically more feasible in relatively skill-intensive manufacturing, such as the automotive and electronics sectors, than in relatively labour-intensive sectors, such as apparel. Most existing studies overestimate the potential adverse employment and income effects of robots, because they neglect to take account of that what is technically feasible is not always also economically profitable. Indeed, the countries currently most exposed to automation through industrial robots are those with a large manufacturing sector, which has a concentration of relatively well-paying activities, such as in the automotive and electronics sectors.

Section C provides cross-country evidence on the evolution of the share of manufacturing in countries' total value added and employment, as well as cross-country and cross-sectoral evidence on robot use. It argues that robots may further the tendency towards a concentration of manufacturing output and employment in a small number of economies, and that they may make upgrading towards more skill-intensive manufacturing more difficult. As such, robots would hamper inclusiveness at the international level. It also shows that countries at more mature stages of industrialization are currently most exposed to robot-based job displacement, as they have the highest intensity of routine tasks for which automation is economically feasible.

Section D argues that country-specific distributional effects from robotics are diverse and depend on a country's stage in structural transformation, its position in the international division of labour, demographic developments, and its economic and social policies. It also argues that some of the adverse employment and income effects that robots could create may well occur in countries that do not use robots. This is because robots boost companies' international cost competitiveness, which may in turn spur exports and thereby make other countries bear at least part of the adverse distributional consequences from robot-based automation through reduced output and employment opportunities. Section E summarizes the main findings and offers some policy conclusions that are further detailed in chapter VII of this *Report*.

B. Distributional effects of technological change

This section addresses the distributional effects of robot-based technological change. The task-based approach to automation is discussed first, followed by an analysis of the impacts of the automation of routine tasks on the production structure of an economy.

1. Automation and routine tasks

Technology can affect employment and income distribution through various channels but, in one way or another, the spread of automation involves firms weighing up the potential savings on labour costs against the cost of investment in the new capital equipment. In the process of automating the production process, the composition of the workforce will also change. The skill-biased technological change framework argues that there is no displacement of labour by capital-embodied technological change. Instead, technology is assumed to complement highly skilled workers and provide them with better employment opportunities, as well as a skill premium on their earnings compared to those of low-skilled workers (Acemoglu and Autor, 2011). Such a skill premium is said to be part of the "race between education and technology" (Goldin and Katz, 2008). This increases gaps in relative wages between skill groups in periods when the skill demands of new technology outrun the skill supply, and decreases such gaps when workers' education catches up with technological advances.

More recently, consensus has shifted towards a labour-displacing view of technological change (Acemoglu and Autor, 2011). A task-based approach has been developed, which hypothesizes that a job is composed of different tasks and that new technology does not always favour better-skilled workers but often complements workers in certain tasks of their job, while substituting for them in others (Autor et al., 2003).[7]

This approach distinguishes between manual, routine and abstract tasks. While many occupations involve a combination of tasks and different manual and routine tasks have been mechanized for centuries, the suggestion is that new technologies, including robots, predominantly substitute labour in *routine* tasks, which are those that can be clearly defined and follow pre-specified patterns, so that they can be coded and translated into the software. Robots have greater difficulty in substituting for more abstract tasks, such as creative, problem-solving and complex coordination tasks, as well as other non-routine tasks, such as those requiring physical dexterity or flexible interpersonal communication, as are often found in the services sector. This means that – from a technical point of view – workers doing routine tasks are most at risk of robot-based automation. It also means that the current wave of automation has increased displacement risks because it is characterized by machines that are technically capable of performing an increasingly wider range of such tasks.

One way of operationalizing the task-based approach and determining the technical feasibility of automation is the calculation of a routine-task intensity index, which links routine tasks to occupations that workers perform on their jobs (Autor and Dorn, 2013; IMF, 2017).[8] This calculation assumes that the task intensity of an occupation is fixed across economic sectors, across countries and over time. The resulting index indicates that routine-based tasks dominate in occupations that are typical for manufacturing, and are mostly performed by medium-skilled workers. The prevalence of routine tasks in manufacturing also indicates that an economy's structural composition is an important determinant of the effect of robot use on inclusiveness.[9]

However, a substitution of labour by capital, including in the form of robots, that is technically feasible will occur only if it also provides economic benefits. The economic profitability of labour-capital substitution has most likely increased in recent years and has probably been concentrated in the substitution of capital for labour engaged in routine tasks. This is because evidence suggests that technological progress has reduced the global price of capital goods relative to that of consumer goods by some 25 per cent between 1975 and 2012 (e.g. Karabarbounis and Neiman, 2014). Most of this decline stems from the size of transistors shrinking so rapidly that every one to two years twice as many of them can be fitted onto a computer chip, reducing the cost of digital computing power embodied in capital goods in the process.[10] The cost of robot-based automation may have further declined because of improved performance of robotics systems, combined with reduced cost of systems engineering (such as programming and installation) and of peripheral equipment (such as sensors, displays and safety structures).

This economic perspective suggests that the cost of automation must be compared with the cost of labour in routine tasks. The latter cost is crucially determined by labour compensation, which, as with the prevalence of routine tasks, tends to vary across different economic sectors, as further discussed in section B.2.[11]

2. Robots and sectoral structure

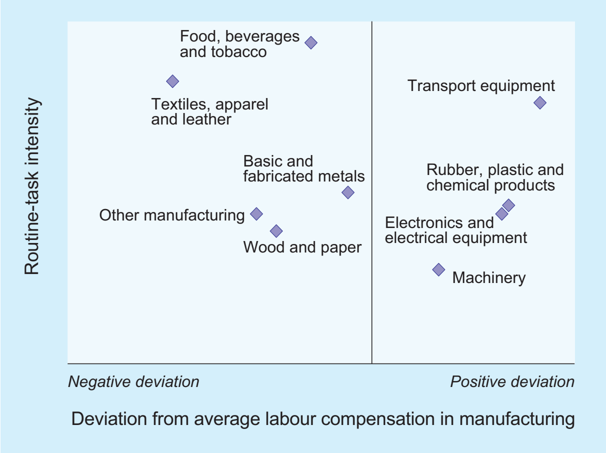
The observation that both the technical and the economic feasibility of automation vary across productive sectors implies that the distributional impact of robot use depends on an economy's structural composition. Accordingly, distributional changes from robots can be analysed in a framework emphasizing changes in economies' structural composition, that is, the changing distribution of output and employment across productive sectors.

An economy's structural composition itself largely depends on two factors. The first is its stage of structural transformation from a largely agrarian to an industrial and eventually services-based economy. Technology may trigger this evolution, with technologically more dynamic sectors enabling production at reduced cost per unit of production. If the resulting increase in productivity in these sectors translates at least partly into a decline in prices, demand for their output, as well as that from other sectors, increases and sets in motion a virtuous circle of growing demand, employment and income. Technologically induced labour-productivity growth makes higher-productivity sectors expand and draw workers away from the other sectors, increasing the economy's aggregate productivity and the number of better-remunerated jobs in the process. This virtuous circle will also tend to facilitate product innovation and create new employment and income opportunities that compensate for any employment lost in the lower-productivity sectors. It is this positive feedback mechanism between manufacturing activities on the one hand and well-paying jobs and thriving innovation on the other that makes maintaining sizeable manufacturing activities a policy objective even for developed countries.

Second, an economy's structural composition is affected by its position in the international division of labour. This position affects distribution not only through sector-specific demand effects, but also through intersectoral changes in the terms of trade. Depending on the structure of global demand, an increase in the volume of global demand, or a shift in relative goods prices, will favour output and employment in some of the economy's sectors more than in others. These impacts from the global economy will affect the domestic dynamics of structural transformation and, hence, changes in the country's pattern of income distribution. A rise in external demand concentrated in manufactures or a change in relative goods prices in favour of manufactures will give an extra boost to higher-productivity activities and technological progress, so that forces from external demand and technology feed on each other.

The critical question is how robots might affect structural change. A sectoral breakdown of manufacturing with respect to the technological and economic feasibility of routine-task automation indicates significant dispersion across manufacturing sectors in terms of both these categories, as shown in figure 3.1. The routine-task intensity index used here is based on an OECD survey that asked workers about the intensity of tasks in their daily work that can be clearly identified as "routine" and follow predefined patterns, so

FIGURE 3.1 Proximate relationship between technical and economic feasibility of routine-task automation, by manufacturing sector



Source: UNCTAD secretariat calculations, based on Marcolin et al., 2016; and the Conference Board, *International Labour Compensation Comparisons* database.

Note: The axes have no scaling to underline the proximate nature of the relationship shown in the figure. All data are for a sample of 20 countries (see text note 12 for details) and refer to the latest available year. The routine task intensity index refers to 2011–2012. Labour compensation reflects sector-specific medians for the period 2008–2014. Calculating labour compensation on the basis of means instead of medians or on data for 2014 instead of 2008–2014 averages, or using larger country samples for labour compensation results in only marginal variation in the cross-sectoral relationship shown in the figure.

that from a technical point of view they can be codified and automated. This index can then be mapped into manufacturing sectors, following Marcolin et al. (2016).[12] While figure 3.1 assumes that a sector's content of routine tasks is fixed across countries, it underlines that exposure to routine-task automation varies significantly across manufacturing sectors.[13] As structural transformation generally involves a shift from lower-wage sectors, such as apparel, towards better-paid sectors, such as the automotive and electronics sectors, and the significance of routine tasks varies across these sectors, exposure to routine-task automation also changes over the course of development.

The estimates in figure 3.1 suggest that the three manufacturing sectors with the greatest intensity in routine tasks are food, beverages and tobacco; textiles, apparel and leather; and transport equipment. This means that the technical feasibility of automating workers' routine tasks appears largest in these three sectors. By contrast, the economic feasibility of routine-task automation (expressed in terms of relative unit labour costs) appears to be greatest in transport equipment, followed by rubber, plastic and chemical products; the electrical and electronics sector; and machinery. The economic feasibility of such automation appears lowest in the textiles, apparel and leather sectors. This suggests that the automotive sector has the greatest potential for robot use, as it combines high technical and high economic feasibility of routine-task automation. In general, as firms probably respond more to economic feasibility, robot-based automation is likely to be concentrated in those manufacturing sectors that are on the right-hand side of the figure. Acting according to technical feasibility would instead mean concentrating robots in those manufacturing sectors that are towards the top of the figure.

The schematic evidence in figure 3.1 could also be interpreted as indicating that ongoing declines in the cost of digital automation will lead to gradual but continued automation of workers' tasks. This would be reflected by increases in routine-task automation in sectors on the left of the figure, thereby reducing the routine tasks performed by workers and labour compensation. However, even if the cost of such automation continues to decline, labour compensation cannot be continuously reduced in the aggregate over a prolonged period. Reduced worker incomes reduce consumption demand and therefore affect the inducement to invest. So, by reducing the effective average cost of labour, automation discourages the investment that would bring in further automation and eventually brings automation to a halt.

C. Industrialization and the international division of labour

The previous section indicated that robot-based automation affects the structural composition of an economy's manufacturing sector. Further, the extent to which robot use impacts the inclusiveness of growth and development also depends on whether manufacturing remains the driver of economic catch-up, and on whether that is determined by the share of manufacturing in output or in employment, given that robots will tend to produce a given level of output at lower levels of employment.

Focusing on the international dimension, this section assesses whether manufacturing activity and employment in recent years have been spread broadly across the world economy or concentrated in a small set of countries. This discussion supplements the historical analysis of *TDR 2016* that provides evidence for premature deindustrialization or stalled industrialization in some developing countries, and that also concluded that the relative size of the manufacturing sector continues to be of crucial importance to an economy's catch-up potential.[14] In this context, country- and sector-specific evidence on the deployment of industrial robots is used to examine whether it has occurred primarily in those countries that have successfully industrialized over the past two decades, or elsewhere. This allows for an assessment of whether robot use tends to enhance past trends in terms of where manufacturing activities are located, or rather work towards reversing such trends.

1. *Salient features of recent industrialization experiences*

Output data measured in current prices show that the world as a whole slightly deindustrialized over the past two decades, mainly as a result of declines

TABLE 3.1 Manufacturing value added, selected economies and groups, 2005 and 2014 shares and 1995–2014 changes

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Current prices						*Constant prices (2005)*			
	Share in total value added			*Share in total goods value added*			*Share in total value added*		*Share in total goods value added*	
	2005 (Per cent)	*2014 (Per cent)*	*Change 1995–2014 (Percentage points)*	*2005 (Per cent)*	*2014 (Per cent)*	*Change 1995–2014 (Percentage points)*	*2014 (Per cent)*	*Change 1995–2014 (Percentage points)*	*2014 (Per cent)*	*Change 1995–2014 (Percentage points)*
World	16.9	16.5	-3.2	52.8	48.5	-9.3	17.9	1.7	55.9	6.8
Developed economies	15.6	14.1	-5.2	58.7	56.3	-6.4	15.2	-0.3	61.1	6.7
Germany	22.4	22.6	-0.1	74.4	73.0	5.9	23.4	1.8	77.4	11.7
Japan	19.9	19.0	-3.2	67.9	68.0	4.2	21.4	2.7	72.5	12.1
United States	13.2	12.3	-4.8	58.2	56.4	-10.3	12.7	-0.0	59.9	7.4
Developing economies	21.1	20.2	-1.2	43.6	43.2	-2.9	23.5	4.7	51.1	12.9
Africa	11.7	10.4	-4.4	23.3	21.3	-9.5	11.6	-1.1	27.2	2.5
Latin America and the Caribbean	17.2	13.5	-4.2	42.7	36.4	-12.1	15.4	-2.2	41.4	-1.8
Mexico	17.3	17.7	-1.9	41.2	43.1	-3.4	16.7	-0.1	43.8	4.3
Asia	24.0	23.2	-1.3	46.9	47.0	-0.4	27.1	6.7	55.6	16.9
China	32.3	28.3	-6.1	54.7	54.0	2.4	34.9	5.7	62.9	15.4
NIEs	25.7	25.3	0.2	73.2	74.6	9.9	29.9	8.6	80.6	20.5
Republic of Korea	28.3	30.3	2.5	69.6	74.7	13.4	32.7	10.7	77.5	22.5
Taiwan Province of China	30.5	30.0	1.0	83.1	80.9	9.0	38.2	12.4	92.6	23.9
Oceania	9.7	8.6	-1.0	25.9	18.4	-6.6	8.4	-1.0	20.7	-5.1
Developing economies, excl. China	18.1	15.7	-3.9	39.7	35.8	-9.1	18.4	1.4	44.1	8.0
Developing economies, excl. NIEs	20.4	19.8		40.3	41.2	-1.8	22.6	4.2	48.0	12.3
Transition economies	18.2	15.3	-5.9	40.9	36.1	-7.1	16.7	-0.6	41.5	2.5
Memo item:	*Share in world manufacturing value added (Per cent)*						*Share in world manufacturing value added (Per cent)*			
Developed economies	68.2	49.7	-27.0				55.9	-18.9		
Developing economies	29.6	47.4	26.0				42.0	18.8		
Developing economies, excl. China	19.9	23.4	6.3				22.8	5.0		
Developing economies, excl. NIEs	24.6	42.5	25.4				35.7	16.3		
Transition economies	2.2	2.8	1.0				2.1	0.1		

Source: UNCTAD secretariat calculations, based on United Nations, Department of Economic and Social Affairs (UN DESA), *National Accounts Main Aggregates* database; and Groningen Growth and Development Centre, *GGDC 10-Sector Database*.
Note: Group data are weighted averages. Manufacturing share for China in 1995 adjusted using the *GGDC 10-Sector Database*. NIEs = newly industrializing economies, including Hong Kong (China), Republic of Korea, Singapore and Taiwan Province of China.

in developed countries and transition economies (table 3.1). For developing countries as a group, the share of manufacturing in total value added fell only marginally and stayed within the long-term average range of 20 per cent to 23 per cent (see also Haraguchi, 2014). As noted in *TDR 2016*, developing countries as a whole have seen their share of global industrial (and manufacturing) output rise steadily since 1980. Between 1995 and 2014, developing countries raised their share in world manufacturing value added by more than 25 percentage points (from 21 per cent to 47 per cent, at current prices), of which almost 20 points are accounted for by China.[15] This increase occurred despite a decline of manufacturing in the total value added of China, which nevertheless continued to exceed the developing country average. Indeed, if both China and the newly industrializing economies (NIEs) of Asia (which on some classifications, such as those used by the International Monetary Fund (IMF) and the United Nations Industrial Development Organization (UNIDO), are considered "advanced economies" or "industrialized economies") are excluded, the share of other developing economies in global manufacturing value added in current prices rose by only 3.6 percentage points (and just 1.6 percentage points in constant terms) over this period. As noted in *TDR 2016*, the attraction of building a robust manufacturing sector comes not only from its potential to generate productivity and income growth but from the fact that such gains can spread out across the economy through production, investment, knowledge and income linkages. It is therefore of some significance that so much of the increase in manufacturing activity was concentrated in China.

Each of sub-Saharan Africa and Latin America and the Caribbean registered significant declines in their already lower-than-average share of manufacturing in total value added. While manufacturing activities in these two groups of countries increased in absolute terms (*TDR 2016*), the decline in manufacturing shares and, hence, deindustrialization in these regions, as well as in developing Oceania, transition economies and developed countries (and most notably in the United States), was accompanied by an increase in the share of output from agricultural and mining activities. This is reflected in the sizeable declines in the share of manufacturing in total goods output in these country groups (table 3.1, column 7).

These deindustrialization tendencies were, in some countries, partly due to relative price developments between manufacturing and other economic sectors, and in particular the decline in the global price of labour-intensive manufacturing, relative to both skill-intensive manufactures and primary commodities (e.g. Fu et al., 2012). In developing Asia, changes in the manufacturing share were strongly positive at constant prices, particularly in China where the substantial fall in the relative price of manufactures was associated with a large increase in the share of manufacturing in total goods output (table 3.1, column 11). Within Latin America, deindustrialization in Mexico was relatively less pronounced than for other countries in the region, and manufacturing shares showed little change when measured in constant prices.[16]

However, stalled industrialization in many developing countries and premature deindustrialization in others, reflect more a combination of unfavourable macroeconomic and institutional conditions, weakening production linkages within and across sectors, insufficient economies of scale, unfavourable integration into global markets and other more structural factors (*TDR 2016*). In general, across developing countries, manufacturing became more concentrated in the larger and richer economies (*TDR 2016*; see also Haraguchi et al., 2017; and Wood, 2017), mostly in Asia.[17] This was largely because of differences in productivity growth: while average productivity in Asia (and especially in East Asia) rose steadily in the 1980s and climbed sharply in the 1990s and 2000s, in both Africa and Latin America it remained essentially flat (*TDR 2016*: figure 3.3). The differences in productivity performance were most marked with respect to manufacturing, which collapsed in the early 1980s in Africa and remained stagnant thereafter, while in Latin America it was more volatile over this period but with no overall gain.

Productivity growth from technological change should make increases in the share of manufacturing in total employment significantly less pronounced than that in output, because of more rapid labour-displacing technological change in manufacturing than in non-manufacturing activities. This tendency can be observed for the world as a whole, given that the employment share of manufacturing slightly declined between 1995 and 2014 (table 3.2), while over the same period that of output measured in constant prices somewhat increased.[18] It can also be observed for transition economies whose sizeable decline in the manufactured employment share significantly exceeded that of their output share, measured in constant prices.

But this is most evident for developed countries.[19] Between 1995 and 2014, these countries' share of manufacturing in total employment fell by more than five percentage points, with that in the United States falling below 9 per cent (table 3.2). Japan experienced an even larger decline than the United States, though its manufactured employment share remained significantly larger than that of the United States. By contrast, Germany recorded a decline in its manufactured employment share between 1995 and 2014 equivalent to only about half that experienced by developed countries taken as a group. Perhaps even more remarkably, Germany experienced an increase in that share between 2005 and 2014.

For developing countries taken as a group, the share of manufacturing in total employment slightly increased between 1995 and 2014 (table 3.2). Once again, manufacturing employment was increasingly concentrated in larger and richer developing countries, though less so than manufacturing output (see also Haraguchi, 2014); and once again China accounted for most of the increase.

TABLE 3.2 Share of manufacturing in total employment, selected economies and groups, 2005 and 2014 shares and 1995–2014 changes

	2005	2014	Change 1995–2014
	(Per cent)		(Percentage points)
World	13.4	13.3	-0.6
Developed economies	14.8	13.0	-5.1
Germany	19.4	19.8	-2.7
Japan	16.9	14.2	-6.3
United States	10.4	8.8	-5.1
Developing economies	13.0	13.3	0.8
Africa	6.3	6.9	1.0
Latin America and the Caribbean	13.0	13.0	-1.2
Mexico	16.6	15.6	-2.1
Asia	14.2	14.7	1.3
China	16.4	18.2	2.8
NIEs	19.9	18.3	-5.4
Republic of Korea	18.5	16.6	-7.0
Taiwan Province of China	27.5	27.4	1.2
Developing economies, excl. China	11.3	11.1	0.2
Developing economies, excl. NIEs	12.9	13.2	0.9
Transition economies	15.9	14.3	-4.3

Source: UNCTAD secretariat calculations, based on Haraguchi et al., 2017; and Wood, 2017.
Note: Data are partly estimated. Group data are weighted averages. The sample used for this table includes 148 economies, of which 33 developed, 99 developing economies and 16 transition economies.

For both Africa and developing countries in Latin America and the Caribbean, the evidence for deindustrialization is stronger for output (table 3.1) than for employment (table 3.2). Africa even registered an increase of manufacturing in total employment, albeit from comparatively low levels and on the basis of a greater extent of estimation of the data (see also Wood, 2017). This is in line with recent evidence that the reallocation of African labour from the primary to the manufacturing sector has been accompanied by a decline of labour productivity in manufacturing (Diao et al., 2017), suggesting very low technological dynamism in African manufacturing.

Evidence in tables 3.1 and 3.2 also indicates that the declines of manufacturing shares of both output and employment that many countries have experienced (giving rise to concerns about widespread premature deindustrialization) have been associated with the increasing concentration of manufacturing activities in a few developing countries. Historical evidence shows that attaining a share of manufacturing above 18 per cent of total employment has been critically important for sustained economic development, and that a high share of manufacturing employment is a significantly better predictor of eventual prosperity than is achieving a high share of manufacturing output (Felipe et al., 2015). This threshold has been attained not only by the developed economies but also by developing economies in Asia, such as China and the now industrialized economies of East Asia, particularly the Republic of Korea and Taiwan Province of China. Once these few successful economies reach a mature stage of industrialization and move to services, the other developing countries may industrialize more easily. Hence, developing manufacturing production and especially attaining a high share of manufacturing in total employment will be as relevant and important for these "follower" countries as it has been for others in the process of economic development.

The question is how robotics affects these developments. If robot use becomes concentrated in those countries where manufacturing also has come to be concentrated, associated improvements in labour productivity and international competitiveness would allow them to prevent a decline, or even achieve an increase, in their own manufacturing activities.[20] As a result, other countries will find it more difficult to move along the traditional path of industrialization. In such countries, the creation of manufacturing employment will tend to be limited to those sectors where robot use has remained constrained either for technical or for economic reasons.

2. Robot deployment: Cross-country and cross-sectoral evidence[21]

The previous section indicated that whether robots will facilitate economic catch-up based on industrialization, or make it more difficult, depends on which countries use robots and in which manufacturing sectors. This section focuses on where robots are used, while box 3.1 discusses where robots are produced and the related benefits reaped.

Despite the hype surrounding the potential of robot-based automation, currently the use of industrial robots globally remains quite small, only around 1.6 million in 2015 as indicated in table 3.3. However, it has increased rapidly since 2010 (figure 3.2), and it is estimated that by 2019 over 2.5 million industrial robots will be at work (IFR, 2016a). Developed

BOX 3.1 The distribution of benefits from robot production

A key element in the distribution of gains from technological change is the return provided to those controlling the knowledge and the machines in which it is embodied. In the case of robot-based automation, the countries and firms that produce robots and those that own the intellectual property embodied in them will benefit from robotics more than other countries and firms. This brings up the key issues of the geographical location of robot production and the extent to which the intellectual property in robots and the associated profits belong to firms in developed or developing countries.

No comprehensive data on the production of industrial robots are available either at the country or firm level. The IFR (2016a) reports country-specific production data only for China, Germany, Japan and Republic of Korea. These four countries accounted for about 83 per cent of the global production of industrial robots in 2015. With 138,160 units, Japan alone still accounted for over half of global production in 2015, even though its share declined from about 61 per cent in 2010 to about 54 per cent in 2015 (see the table in this box). The Republic of Korea followed with a share of about 12 per cent, and China and Germany, each having around an 8 per cent share in 2015. While all the industrial robots produced in China appear to be used within China, Germany and Japan exported more than three quarters of their production in 2015. In the same year, the Republic of Korea exported about one fifth of its production, but imported more than twice as many units. Germany also imported slightly more industrial robots than it exported in 2015, while imports to Japan amounted to less than 1 per cent of the country's production in 2015.

Production of industrial robots, world and selected countries, 2010–2015

	2010	*2011*	*2012*	*2013*	*2014*	*2015*
	Number of units ('000)					
World	120.6	166.0	159.3	178.1	220.6	253.7
	(Percentage shares)					
China	n.a.	n.a.	n.a.	5.3	7.2	8.0
Germany	9.8	11.4	11.6	11.1	9.4	7.8
Japan	61.3	59.1	59.8	53.6	54.8	54.4
Republic of Korea	14.2	12.8	10.0	8.9	12.2	12.6
Other countries	14.7	16.7	18.6	21.0	16.4	17.1

Source: UNCTAD secretariat calculations, based on IFR, 2016a.

Firm-level data for 2016 confirm the continued significance of Japan in the global production of industrial robots.[a] Three of the top four (accounting for 73 per cent of these four companies' production) and five of the top ten (62 per cent) globally leading robot-producing firms are Japanese. These firm-level data also indicate that Switzerland and the United States are likely to account for the bulk of the 18 per cent of the country-specific production data for 2015 which are not disaggregated by the IFR (2016a).

However, neither country- nor firm-specific data fully reveal where the economic benefits of robot production actually occur, because most robot suppliers produce in several countries. Moreover, a specific supplier may actually be owned by another firm from another country, such as the German robot maker KUKA, which is among the world's biggest robot suppliers and which was purchased by the Chinese company Midea in 2016 (IFR, 2016a: 164–165).

But most importantly, these data do not indicate where innovation takes place and, thus, innovation benefits are reaped. Data on robotics clusters – geographically proximate groups of interconnected companies and institutions active in robotics – indicate that in 2015 at least 72 per cent of them were located in developed countries, and that the United States alone accounted for 40 per cent of the geographical location of robotics clusters (Keisner et al., 2015). The only developing countries identified among the world's main geographical locations of robotics clusters in that year were China and the Republic of Korea, accounting for 5 per cent and 3 per cent, respectively, but with rapidly increasing importance. The vast majority of patent applications in robotics also come from the developed countries with, however, a significantly faster increase in the Republic of Korea since the early 2000s and China more recently. At the sectoral level, automotive and electronics companies file most of the patents related to robotics (Keisner et al., 2015).

Data indicating a strong increase in patent filings from China could suggest that robotics reduces the technology gap between developed and developing countries and that an increasing share of the benefits from innovation in robotics accrues to some developing countries. However, governments often encourage innovation through the provision of financial support that is contingent on patent filing, so patent filings may not always have a close link with significant innovation but rather be a means employed by firms to benefit from such financial support. For example, there is a perception that, as in several other countries that offer such incentives, only a small part of all patents filed in China can be classified as "invention" patents, and that Chinese firms actually file patents to receive cash bonuses, subsidies or lower corporate income taxes from the government.[b] Should such a quality gap actually exist, it may nonetheless be closing, given the substantial spending on education and research by China (see, for example, Kozul-Wright and Poon, 2017).

a Abdul Montaqim, "Top 14 industrial robot companies and how many robots they have around the world", Robotics and Automation News, available at: https://roboticsandautomationnews.com/tag/top-10-robotics-companies-in-the-world/ (accessed 16 May 2017).

b For this view see, for example, Margit Molnar, "Making the most of innovation in China", oecdecoscope, 10 April 2017, available at: https://oecdecoscope.wordpress.com/2017/04/10/making-the-most-of-innovation-in-china/.

TABLE 3.3 Industrial robots: Estimated annual installation and accumulated stock, selected economies and groups, 2010–2015[a]

	Annual installation						Stock of operational robots	Change in stock of operational robots
	2010	2011	2012	2013	2014	2015	2015	2010–2015
	('000 of units)							(Per cent)
World	120.6	166.0	159.3	178.1	220.6	253.7	1 631.7	54.1
	(Percentage shares)							
Developed economies	56.6	56.4	58.9	52.0	46.3	45.2	58.7	15.3
France	1.7	1.8	1.9	1.2	1.3	1.2	2.0	-6.8
Germany	11.7	11.8	11.0	10.3	9.1	7.9	11.2	23.3
Italy	3.7	3.1	2.8	2.6	2.8	2.6	3.8	-1.8
Japan	18.2	16.8	18.0	14.1	13.3	13.8	17.6	-6.9
United Kingdom	0.7	0.9	1.8	1.4	0.9	0.6	1.1	29.2
United States	11.9[b]	12.4	14.1	13.3	11.9	10.8	14.4[b]	42.4[b]
Developing economies	41.0	39.2	37.7	44.8	50.1	52.9	39.1	185.7
Africa	0.2	0.2	0.2	0.4	0.2	0.1	0.3	84.3
Latin America and the Caribbean	1.4[b]	2.3	2.5	2.5	1.9	2.8	2.0[b]	162.2[b]
Mexico	0.7[b]	1.2	1.3	1.5	1.1	2.2	1.2[b]	234.7[b]
Asia	39.4	36.7	34.9	42.0	48.0	49.9	36.8	188.2
China	12.4	13.6	14.4	20.5	25.9	27.0	15.7	390.5
NIEs	22.9	18.5	15.1	15.9	14.9	19.0	16.7	106.1
Republic of Korea	19.5	15.4	12.2	12.0	11.2	15.1	12.9	108.2
Taiwan Province of China	2.7	2.2	2.1	3.1	3.1	2.8	3.0	83.0
Developing economies, excl. China	28.6	25.6	23.2	24.3	24.2	25.9	23.3	123.0
Developing economies, excl. NIEs	17.9	20.1	22.0	28.1	34.6	33.2	22.4	300.7
Transition economies	0.2	0.2	0.3	0.4	0.2	0.1	0.2	172.9
Other economies	2.2	4.2	3.1	2.8	3.4	1.8	2.0	n.a.

Source: See figure 3.2.

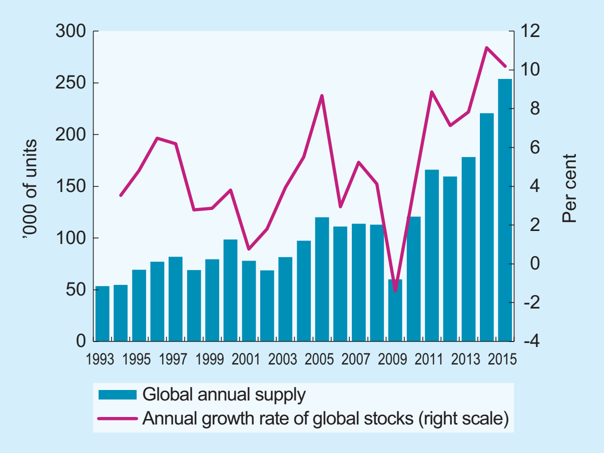
a The IFR calculates the operational stock of robots by accumulating annual deployments and assuming that robots operate 12 years and are immediately withdrawn after 12 years, except for those countries, such as Japan, that undertake robot stock surveys or have their own calculation of operational stock and where these country-specific data are used.

b Estimations based on data reported as an aggregate until 2010 by the IFR database for North America (Canada, Mexico and the United States) and disaggregated annual data provided by the IFR through private exchange.

countries accounted for 60 per cent of the stock in 2015, with just the three countries – Germany, Japan and the United States – making up 43 per cent.[22] However, table 3.3 shows that their shares in annual deployment have been falling over time, particularly in Japan. By contrast, the recent increase in industrial robot deployment has been the most rapid in developing countries, but this too has been heavily concentrated and is mostly due to China.

Between 2010 and 2015 the stock of industrial robots in China quadrupled, with the increase almost four times that of the Republic of Korea. By 2015, the share in the global stock of industrial robots held by China exceeded that in Germany and the United States while remaining slightly short of the share of Japan. As a result, just three Asian countries – China, Japan and Republic of Korea – accounted for 46 per

FIGURE 3.2 Industrial robots: Global annual installation and annual growth of estimated global stocks, 1993–2015



Source: UNCTAD secretariat calculations, based on the IFR database.

cent of the estimated global stock of industrial robots in 2015. All developing countries excluding China and the Asian NIEs (which, as already mentioned, on some classifications, such as those used by the IMF and UNIDO, are considered "advanced economies" or "industrialized economies") accounted for less than 7 per cent of the global stock. In Latin America and the Caribbean, Mexico alone accounts for the bulk of the region's industrial robot deployment, having registered a very large increase in the stock of industrial robots over the past few years. There are hardly any robots in Africa.

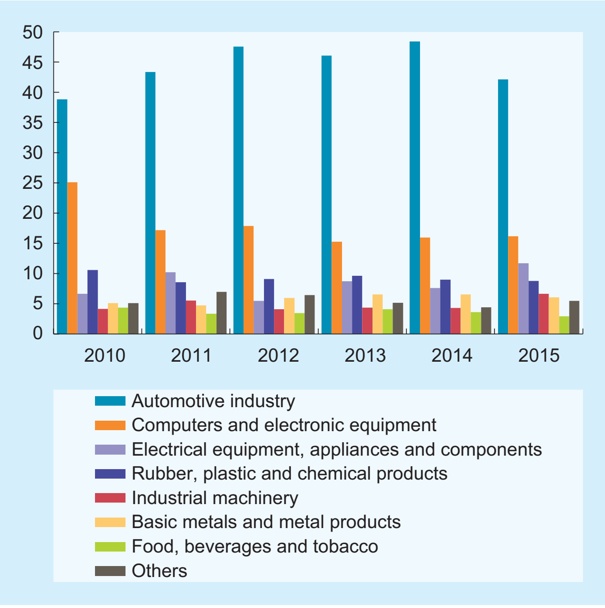
The use of industrial robots is also heavily concentrated in just five sectors: the automotive industry that accounted for 40 per cent to 45 per cent of annual deployment between 2010 and 2015, followed by computers and electronic equipment (about 15 per cent), electrical equipment, appliances and components (5 per cent to 10 per cent), closely followed by the group of rubber, plastic and chemical products, and by machinery (figure 3.3).

Given the evidence in table 3.3 and figure 3.3, it is not surprising to see the heavy concentration in a few countries of robot use in specific industrial sectors. This may be illustrated for the automotive industry where, in the context of the already rapid increase in robot deployment in this sector as a whole between 2010 and 2015, the share of China in annual deployment steadily increased to reach almost 25 per cent in 2015 (figure 3.4). The remaining share was distributed among Germany, Japan, Mexico, the Republic of Korea and the United States.

The large absolute size of the manufacturing sector in China is in part responsible for this country's large share in the global stock of industrial robots. However, robot density (the number of industrial robots in manufacturing per manufacturing employee) is the highest in developed countries and developing countries at mature stages of industrialization (figure 3.5). The other developing countries with the highest recorded robot density, are Thailand, which ranks twenty-fifth, Mexico, which ranks twenty-seventh, Malaysia, which ranks thirty-first and China, which ranks thirty-fifth.[23] Given the sectoral concentration of robot deployment, it is not surprising that robot density in the automotive industry is larger than in total industry for all economies for which data are available (IFR, 2016a). Yet, it is interesting to note that this difference for developing countries is on average considerably larger than that for developed countries. This indicates that the sectoral concentration of robot density is particularly high in developing countries.

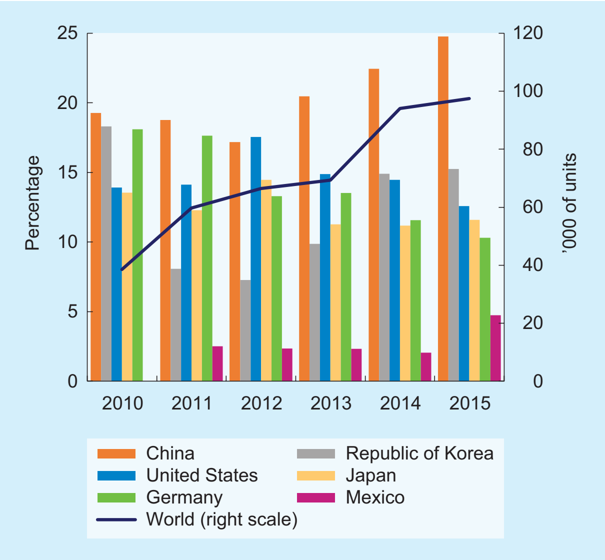
FIGURE 3.3 Industrial robots: Global annual installation, by manufacturing sector, 2010–2015

(Percentage of total robots in manufacturing)



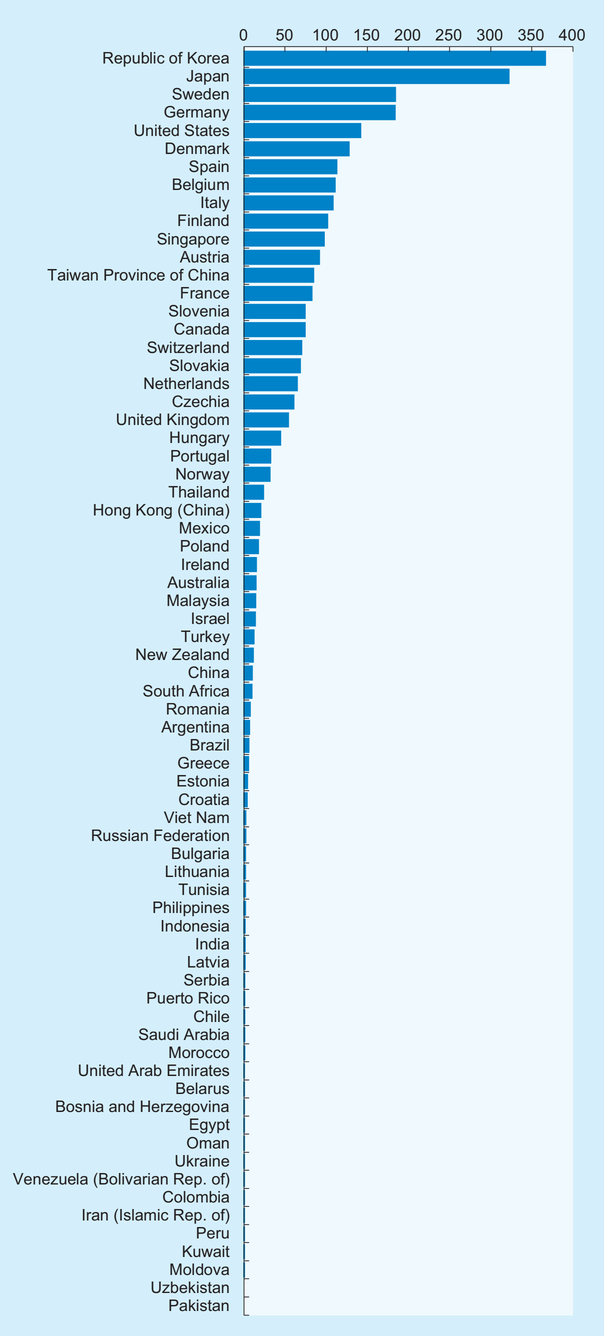
Source: See figure 3.2.

FIGURE 3.4 Industrial robots in the automotive industry: Annual installation, world and selected countries, 2010–2015



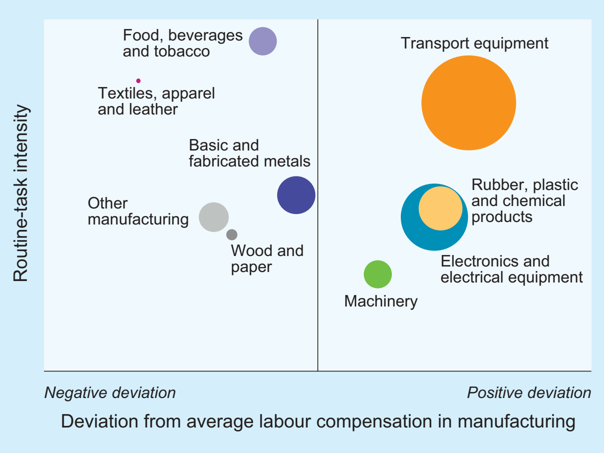
Source: See figure 3.2.

FIGURE 3.5 Estimated robot density in manufacturing, 2014
(Units of industrial robots per 10,000 employees)



Source: UNCTAD secretariat calculations, based on the IFR database; and Wood, 2017.
Note: The figure shows data for all those 70 economies for which data are available.

FIGURE 3.6 Proximate relationship between technical and economic feasibility of routine-task automation, and estimated stock of industrial robots, by manufacturing sector

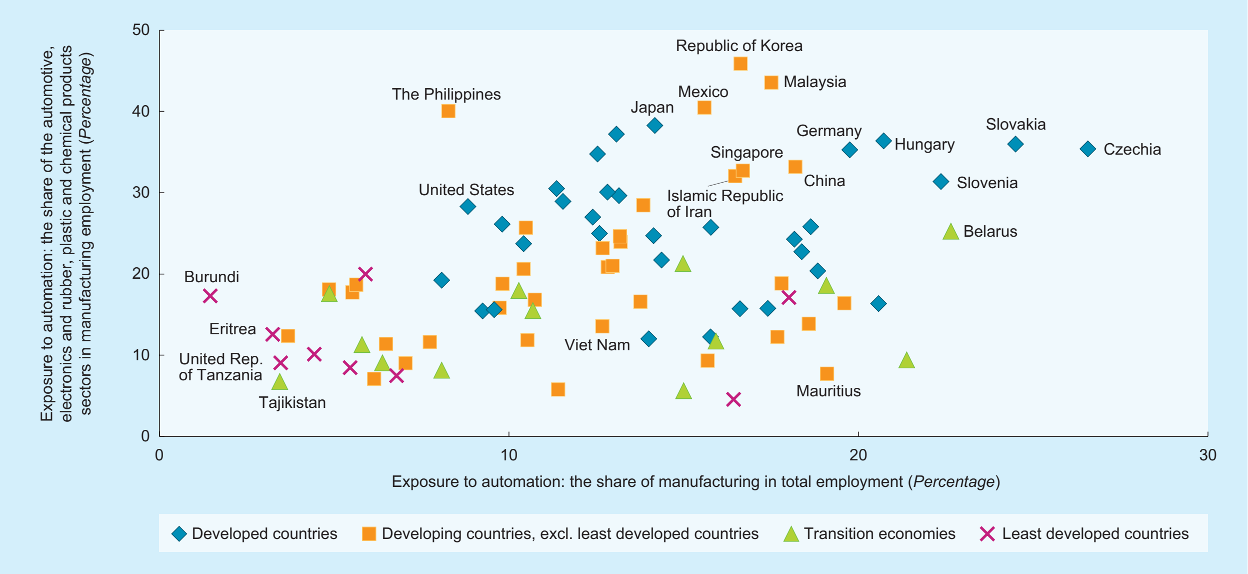


Source: UNCTAD secretariat calculations, based on Marcolin et al., 2016; the Conference Board, *International Labour Compensation Comparison* database; and the IFR database.
Note: The axes have no scaling to underline the proximate nature of the relationship shown in the figure. Bubble sizes reflect the stock of industrial robots. All data are for a sample of 20 countries (see text note 12 for details) and refer to the latest available year. The routine task intensity index refers to 2011–2012. Labour compensation reflects sector-specific medians for the period 2008–2014. Robot data refer to 2015. Calculating labour compensation on the basis of means instead of medians or on data for 2014 instead of 2008–2014 averages, or using larger country samples for labour compensation and stocks of robot results in only marginal variation in the cross-sectoral relationship shown in the figure.

To examine how actual robot deployment has navigated the trade-off between technical and economic feasibility, robot deployment can be added into figure 3.1. Doing so (figure 3.6) shows that robot deployment has been concentrated in those manufacturing sectors that are on the right-hand side of the figure, rather than at its top.[24] This suggests that economic factors are more important for robot deployment than the technical possibilities of automating workers' tasks. However, both technical and economic feasibility appear to be important: the bubble with the largest size, transport equipment, is also the topmost of the four sectors on the right-hand side of the figure; and the bubble sizes increase along the upper right quadrant, as routine-task intensity and unit labour costs both increase.

The figure also suggests that robot deployment has remained very limited in those manufacturing sectors where labour compensation is low, even if these sectors have high values on the routine-task intensity index. Robot deployment in the textiles, apparel and leather sector has been lowest among all manufacturing sectors even though this sector ranks second in terms of the technical feasibility of automating workers' routine tasks. It should be noted, however, that reduced robot adoption may also be related to technology issues of automation unrelated to workers'

FIGURE 3.7 Proximate current vulnerability to robot-based automation in manufacturing, selected economies



Source: UNCTAD secretariat calculations, based on Wood, 2017; and UNIDO, *Industrial Statistics* database.
Note: The horizontal axis reflects the share of manufacturing in total employment in 2014. The vertical axis reflects the share of the automotive sector, of the electronics sector and of the rubber, plastic and chemical products sector in manufacturing employment as an average for the period 2010–2014 over the years for which data are available. The sample includes all 91 economies for which data are available.

tasks, such as the pliability of fabrics in the apparel sector and the need to insert small flexible parts into tightly packed consumer electronics (Kucera, 2017).

Consideration of economic, in addition to technical, feasibility also bears on the gender impact of workplace automation. Studies only looking at technical feasibility (e.g. World Economic Forum, 2016; World Bank, 2016) find that the number of job losses is broadly the same for women and men. Yet, women are comparatively more affected because their participation in the labour force is lower, and because they are more likely to be rationed out of emerging jobs in areas that are complementary to robot use, for reasons elaborated in the next chapter. However, taking account of economic feasibility and low robot deployment in light manufacturing, such as apparel, where female employment tends to be concentrated, the gender impact of workplace automation may be reversed. A study for the United States, for example, found job displacement effects for both men and women, but the adverse effects for men were about 1.5–2 times larger than those for women (Acemoglu and Restrepo, 2017).

The concentration of robots in the automotive and electronics sectors, shown in figure 3.6, suggests that robot-based automation has, for now, largely left unaffected the initial stage of industrialization and establishment of labour-intensive manufacturing activities based on traditional labour-cost advantages, while it might well complicate subsequent industrial upgrading. Indeed, on current technological and economic indicators, developed countries and developing countries other than least developed countries (LDCs) would seem to be exposed to robot-based automation in manufacturing to a larger extent than LDCs (figure 3.7).

It should be noted that this evidence only refers to exposure to robot-based automation and does not take account of the risks to employment from other forms of automation. But it suggests that robot-based automation per se does not invalidate the traditional role of industrialization as a development strategy for lower income countries. Yet, the greater difficulty in attaining sectoral upgrading may limit the scope for industrialization to low-wage and less dynamic (in terms of productivity growth) manufacturing sectors. This could seriously stifle these countries' economic catch-up and leave them with stagnant productivity and per capita income growth.

At the same time, however, countries specialized in lower-wage labour-intensive manufacturing may benefit from favourable terms of trade effects. This will be the case if the concentration of robots in higher-wage skill-intensive manufactured goods translates at least partly into a global decline in the prices of such goods and reverses the trend decline in the global price of labour-intensive manufacturing relative to both skill-intensive manufactures and primary commodities that occurred over the past two decades.

3. Robots and reshoring

Robot use in low-wage labour-intensive manufacturing has remained low. Even so, developing countries' employment and income opportunities in these sectors may be adversely affected by the reshoring of manufacturing activities and jobs to developed countries. This would reduce the ability of developing countries to benefit from the special economic advantage that manufacturing confers in terms of economic catch-up.[25]

One element of this special economic advantage of manufacturing is its superior potential for the division of labour. This potential has, for example, been the basis for global value chains and the offshoring of certain labour-intensive manufacturing tasks from higher-wage to lower-wage economies. In developed countries, offshoring has enabled a shift in output from less productive to more productive manufacturing activities. And it has allowed some developing countries to move from low-productivity agricultural to higher-productivity and often labour-intensive manufacturing activities.[26] However, there is significant variation in the employment effects of offshoring in manufacturing across developed countries. Analysis of input–output data for the period 1995–2008 indicates sizeable losses of manufacturing employment from manufacturing value chains for the United States, as well as Japan, while the number of such jobs remained stable in Germany (Timmer et al., 2015).[27]

Adverse employment effects from offshoring combined with indications of an erosion of developing countries' labour-cost advantage may have triggered some reshoring of manufacturing activities to developed countries.[28] However, there is only fragmented and anecdotal evidence of the significance of reshoring.[29] Survey results and responses to firm-level questionnaires that aim to provide broader and more systematic evidence indicate that offshoring continues, but also that some reshoring has occurred at a slow pace and across all industrial sectors, albeit at different intensities and for different motives (Fratocchi et al., 2015; Cohen et al., 2016; Stentoft et al., 2016). Moreover, an important part of new manufacturing activities in the United States relates to offshoring by European and Asian firms in relatively advanced manufacturing sectors, rather than to a reshoring by firms in the United States of labour-intensive manufacturing from developing countries (Cohen et al., 2016). Shifting production sites among these developed countries may have been facilitated by the greater compatibility of technology platforms.

Evidence also shows that where reshoring to developed countries has occurred, it has fallen short of expected employment effects. Reshoring has mostly been accompanied by capital investment, such as in robots, with the little job creation that has occurred concentrated in high-skilled activities (De Backer et al., 2016). This means that jobs that "return" with reshored production will not be the same as those that have left.

Indeed, reshoring is likely to be more about manufacturing output rather than employment, given the positive relationship between manufacturing output growth and productivity growth.[30] Evidence for the United States in the period 1991–2007, for example, indicates that firms in sectors where manufactured output declined and that experienced greater exposure to import competition from China also saw a decline in both their patent output and research and development (R&D) expenditure (Autor et al., 2016). This finding may raise concerns that production offshoring stifles innovation and, thus, reduces productivity growth in manufacturing.[31] An additional argument that links manufacturing output and innovation concerns the advantages of locating production geographically close to product design, as manufacturing competence is integral to innovation (Pisano and Shih, 2012).[32]

Given that design and innovation activities have not been offshored, this reassessment would recommend reshoring production because shorter supply chains would stimulate innovation and product development. Such a motivation would not only trigger reshoring but also the relocation of production activities to areas where firms expect that links between production and R&D, and its positive impact on innovation, can be best encouraged. Recognition of such links between manufacturing output, innovation and technology growth led to the creation of the National Network for Manufacturing Innovation in the United States, which was formally established in 2014 and is now known as Manufacturing USA. The initiative's main aim is "to support industry in establishing the ecosystems or industrial commons that will better enable innovators to develop the specific manufacturing technologies, processes, and capabilities needed to advance promising early stage technological inventions that can be scaled-up and commercialized by U.S. manufacturers" (Executive Office of the President of the United States, 2016: vii). But it also aims at encouraging manufacturers to locate production facilities in the United States (e.g. Hart et al., 2012). All this suggests that reshoring depends on factors that go significantly beyond simple labour-cost comparisons, which have driven offshoring decisions. This also suggests that developed countries may increasingly use robots to facilitate the reshoring of manufacturing production with a view to stimulating further technological progress, including in terms of product innovation. This would most likely have adverse effects on the inclusiveness of growth at the international level.

One reason why the pace of reshoring has, nevertheless, remained slow may be tepid investment and sluggish aggregate demand in developed countries more generally. Moreover, these countries lack the supplier networks that some developing countries have built to complement assembly activities. And while labour-cost differentials remain a factor in firms' decisions of where to locate production, especially of goods with a high labour content, demand factors such as the size and growth of local markets are becoming increasingly important determinants. Accordingly, many companies that once moved production to, say, China, are now staying there for access to growing local demand. This suggests that the production of labour-intensive manufactures destined for rapidly growing markets in large developing countries with domestic production linkages is unlikely to be reshored.

D. Productivity and inclusiveness at national level

This section examines the relationship between robot use on the one hand and productivity, output, employment and wages in manufacturing on the other hand, within national economies.

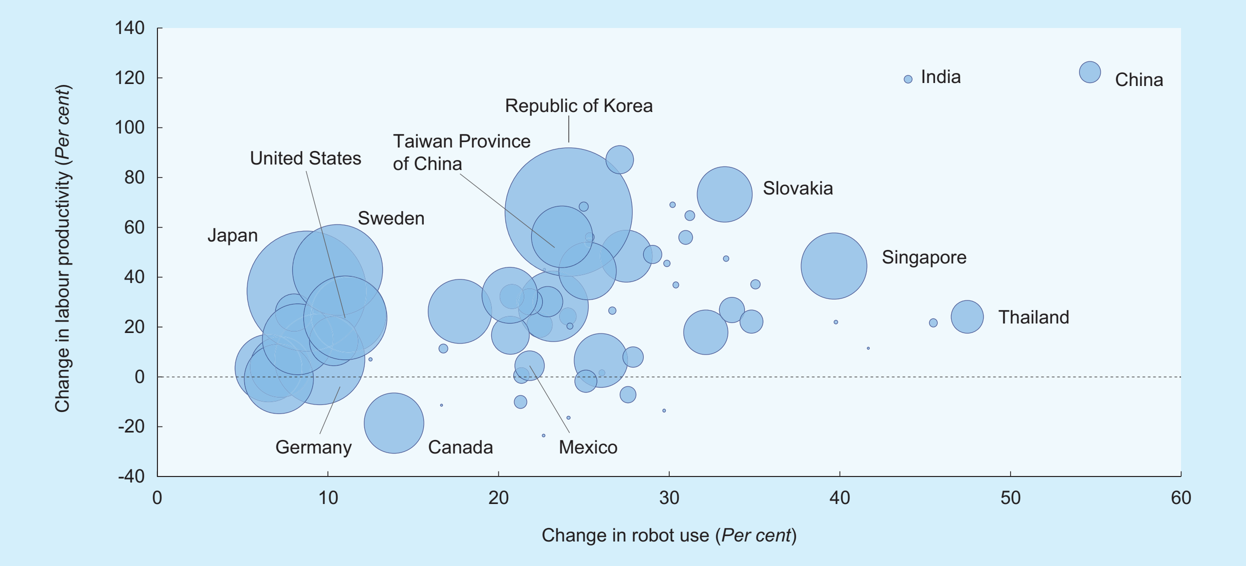
Robot deployment has been associated with productivity growth (figure 3.8).[33] This positive association can be observed both for countries with relatively large robot density – such as Germany, Japan, Republic of Korea and the United States – and for economies with more modest robot density but rapidly increasing robot stocks – such as China and Taiwan Province of China.

Cross-country evidence for the same period suggests a positive relationship between increased robot use and an increased share of manufacturing in total value added. This relationship holds in particular for those economies where robot density is comparatively large (figure 3.9A). The evidence for any such relationship in economies with comparatively small robot density is somewhat less clear (figure 3.9B). But it is worth noting that many countries where industrial robot use is low also experienced deindustrialization in terms of a shrinking share of manufacturing in total value added. Figure 3.9 supports the finding in the previous section that robot use tends to foster the concentration of manufacturing activity in a small number of countries.

Cross-country evidence for the same sample points to a slight negative relationship between changes in robot use and changes in the share of manufacturing in total employment (figure 3.10). Given the evidence on a positive relationship between robot use and labour productivity, and considering that the very purpose of using robots is to automate certain tasks, this finding is not surprising in itself.

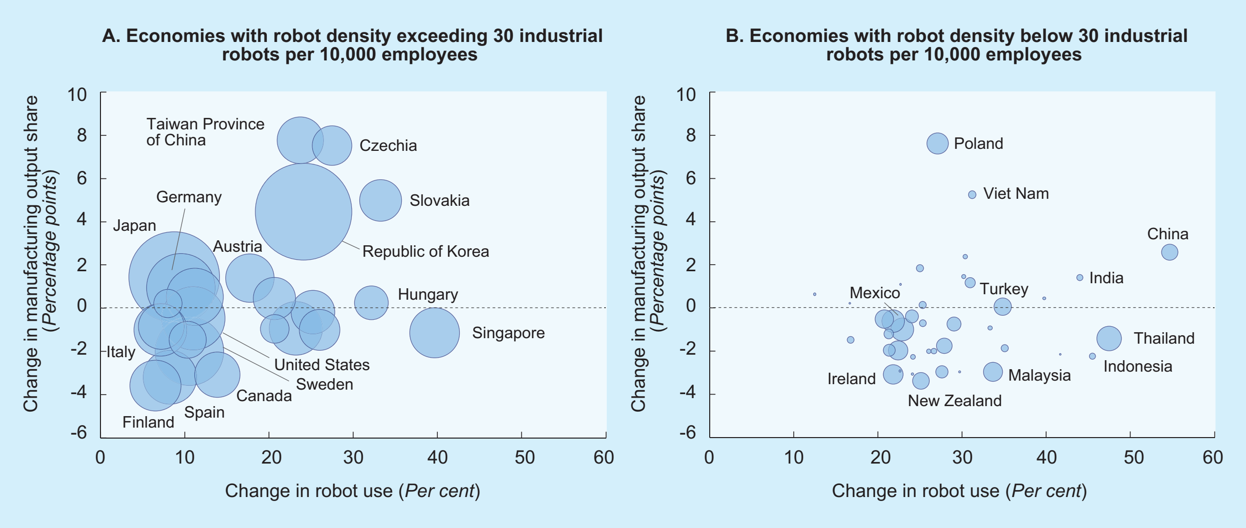
Rather, it is interesting to note that some countries where robot density is large, including Germany and the Republic of Korea, as well as countries where the accumulation of robots has been rapid, such as China, experienced an increase, or only a small decline, in the share of manufacturing in total employment. China and Germany also experienced an increase in the absolute number of manufacturing jobs, while the Republic of Korea recorded a small decline (figure 3.11). While there appears to be little systematic relationship between changes in robot use in manufacturing and changes in real wages in manufacturing across the group of economies for which

FIGURE 3.8 Robot use and labour productivity in manufacturing in selected economies: Change between 2005 and 2014



Source: UNCTAD secretariat calculations, based on the IFR database; and Wood, 2017.
Note: Change in robot use reflects the percentage change in the ratio of the average annual robot installation and the average robot stock over the period 2005 and 2014. Change in labour productivity reflects the percentage change in labour productivity in manufacturing between 2005 and 2014. The size of the bubbles reflects robot density in 2014. The chart includes the 64 economies for which data are available.

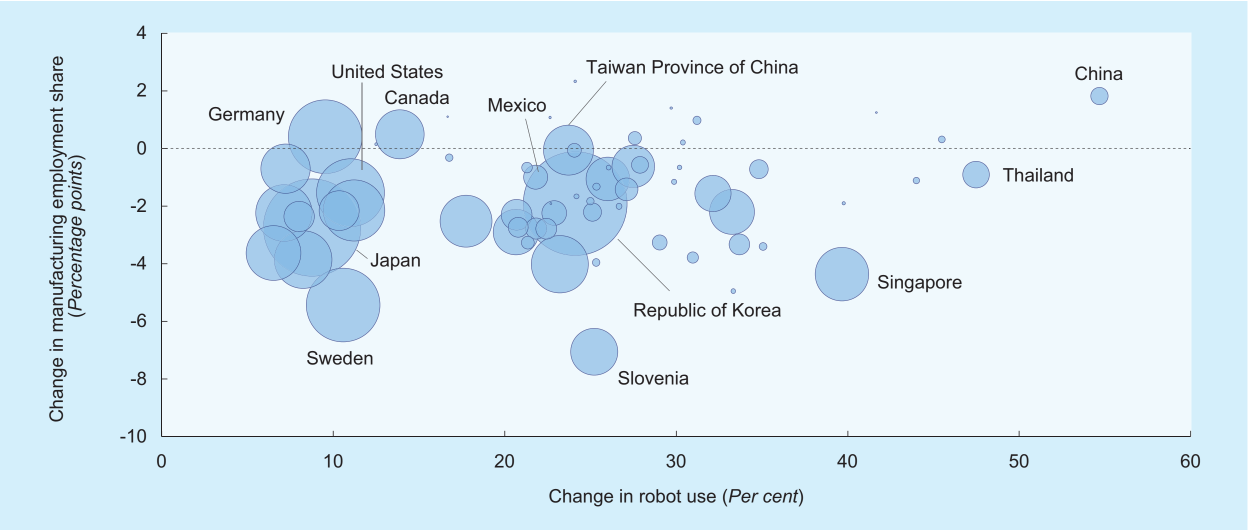
FIGURE 3.9 Robot use and manufacturing output share in selected economies: Change between 2005 and 2014



Source: See figure 3.8.
Note: Change in robot use reflects the percentage change in the ratio of the average annual robot installation and the average robot stock over the period 2005 and 2014. Change in manufacturing output share reflects the percentage point change in the share of manufacturing in total value added between 2005 and 2014. The size of the bubbles reflects robot density in 2014. The figures include the 64 economies for which data are available, of which 24 economies in figure 3.9A and 40 economies in figure 3.9B.

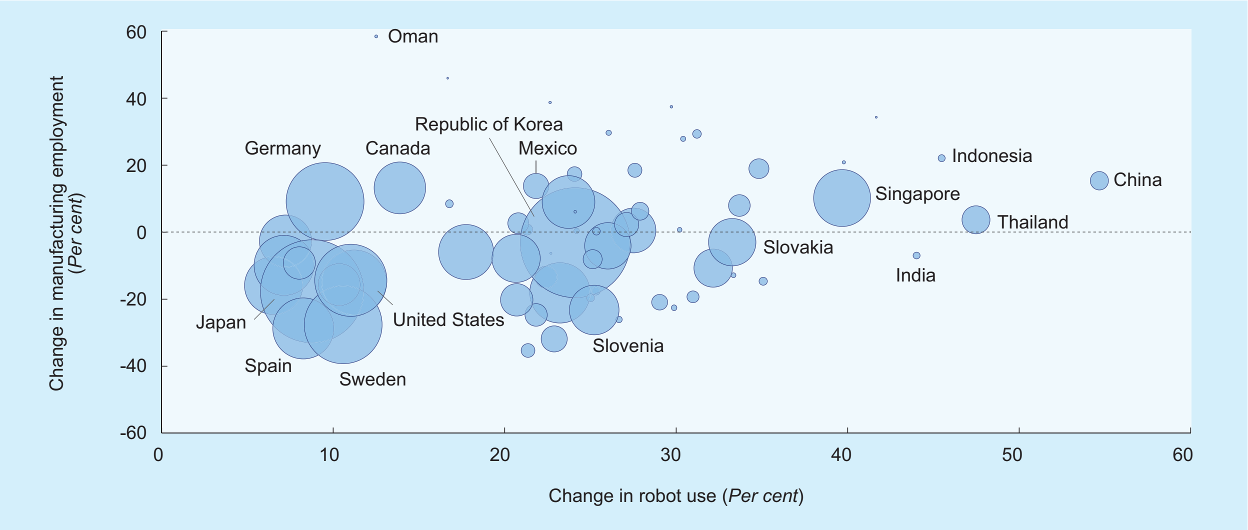
data are available, increased robot use was associated with real wage growth in all economies except Mexico, Portugal and Singapore which recorded small declines (figure 3.12). Growth of both real wages and robot use was particularly large in China (at roughly 150 per cent and 55 per cent, respectively).[34]

FIGURE 3.10 Robot use and manufacturing employment share in selected economies: Changes between 2005 and 2014



Source: See figure 3.8.
Note: The size of the bubbles reflects robot density in 2014. Change in robot use reflects the percentage change in the ratio of the average annual robot installation and the average robot stock over the period 2005 and 2014. Change in manufacturing employment share reflects the percentage point change in the share of manufacturing in total employment between 2005 and 2014. The figure includes the 64 economies for which data are available.

FIGURE 3.11 Robot use and manufacturing employment in selected economies: Changes between 2005 and 2014

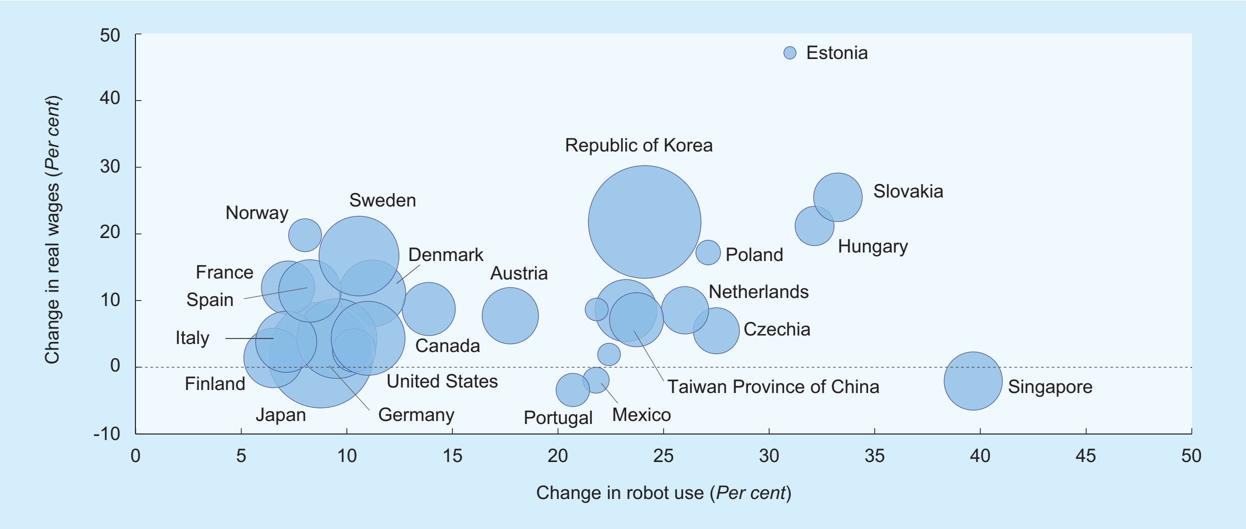


Source: See figure 3.8.
Note: The size of the bubbles reflects robot density in 2014. Change in robot use reflects the percentage change in the ratio of the average annual robot installation and the average robot stock over the period 2005 and 2014. Change in manufacturing employment reflects the percentage change in manufacturing employment between 2005 and 2014. The figure includes the 64 economies for which data are available.

This indicates that the impact of robot-based automation on manufacturing employment has varied greatly across countries. It clearly depends on country-specific conditions, including institutional arrangements (such as workers' bargaining power), macroeconomic conditions and processes, and country-specific robotics initiatives (as illustrated for China in box 3.2).

Economic policies greatly affect the impact of automation on aggregate demand. If productivity gains

FIGURE 3.12 Robot use and manufacturing wages in selected economies: Changes between 2005 and 2014



Source: UNCTAD secretariat calculations, based on the IFR database; OECD Statistical Database; and *Chinese Statistical Yearbook 2016*.
Note: The size of the bubbles reflects robot density in 2014. Change in robot use reflects the percentage change in the ratio of the average annual robot installation and the average robot stock over the period 2005 and 2014. Change in manufacturing wages reflects the percentage change in real manufacturing wages between 2005 and 2014. The figure includes the 28 economies for which data are available except China, which is an outlier along both axes and whose inclusion would blur the picture.

are shared and real wages grow in line with productivity growth, automation will tend to boost private consumption, aggregate demand and ultimately total employment. Obviously, in such cases an important role is played by macroeconomic policies that operate to sustain effective demand, employment and standards of living within a country.

Even if that is not the case, for some countries, employment could remain stable or even increase if the additional supply that results from automation-based productivity growth is absorbed through increased demand from exports. This would mean that any adverse employment and income effects of automation are transferred to other countries through trade. Germany and Mexico provide examples of this type, where an export-oriented strategy appears to have partially avoided the adverse effects of robot use on domestic employment.

In the case of Germany, the sizeable increase in robot density in the automotive sector from an already high base was associated with strong expansion of output and productivity and accompanied by a sizeable but somewhat smaller expansion of employment and real wages (table 3.4). This combined to produce a reduction in unit labour costs by about 10 per cent between 2007 and 2015. The favourable effect of automation on employment was facilitated by rapid increase in the sector's exports, which helped to increase the trade surplus of Germany in this sector alone to more than 4 per cent of GDP in 2015. While the other highly automated manufacturing sectors – such as rubber and plastic products, pharmaceuticals and metals products – showed slightly less impressive growth, all of them contributed positively to the sizeable trade surplus of Germany.

Mexico is another interesting example, as the country combines significant automation in the automotive sector (accounting for 20 per cent share of manufacturing employment in 2015), more modest automation in electronics (about 12 per cent of manufacturing employment), and virtually no robot use in textiles and apparel (9 per cent of manufacturing employment). It is noteworthy that the sectors where automation increased most between 2011 and 2015 were also those with the largest output gains (table 3.4).[35] In the automotive sector excluding parts, for example, robot density increased from 121 robots per 10,000 employees in 2011 to 513 robots per 10,000 employees in 2015, with this sector's output growth vastly exceeding that of the manufacturing sector as a whole. A similar but smaller expansion was evident for the electronics sector, industrial machinery, and rubber and plastic products. The increased use of robots in Mexico has also been associated with expanding employment. As in

BOX 3.2 **National robot strategy: The case of China**

The "Made in China 2025" initiative by China is often considered to have been inspired by the "Industry 4.0 Strategy" of Germany (e.g. European Chamber of Commerce in China, 2017). Launched in 2015, "Made in China 2025" aims to turn its economy into a world manufacturing powerhouse by 2049, coinciding with the centenary of the founding of the People's Republic of China.[a] Its guiding principles are to make manufacturing innovation-driven, emphasize quality over quantity, achieve green development, optimize the structure of Chinese industry, and nurture human talent (Wübbeke et al., 2016; Kozul-Wright and Poon, 2017). In its thirteenth Five-Year Plan, adopted in March 2016, the Chinese Government sets out how to deepen the implementation of this strategy over the period 2016–2020. In support of the manufacturing targets, the government set up the CNY20 billion Modern Manufacturing Industry Investment Fund, CNY6 billion of which are allocated from the government budget (OECD, 2017). It also relies on private sector initiatives, including by calling on firms to self-declare their own technology standards and participate in international standards setting.

Given its emphasis on digitization and modernization of manufacturing, robots play an essential role in the strategy of China in terms of both their increased use and enhanced domestic production. The Development Plan for the Robotics Industry 2016–2020, issued in April 2016, aims at increasing robot density to 150 robots per 10,000 employees, as well as at increasing domestic production to 100,000 industrial robots per year.[b] According to data for 2015 from the IFR (2016a), this would imply a tripling in both robot use and domestic production. While robot use has been led by the automotive sector in the past few years, the electronics sector is envisaged to drive increased robot use in the next two or three years.[c]

The objective of guiding manufacturing away from labour-intensive and low value added activities to a set of manufacturing activities of a more capital-, high-skill- and knowledge-intensive nature is related to rising wage costs in these traditional export industries (Wei et al., 2016; *TDR 2010*, chap. II). Hence, manufacturers in China may feel pressured on the one hand by the labour-cost advantage of less-developed countries with far smaller domestic markets and, on the other hand, by the advanced economies that themselves have formulated initiatives supporting further development of their manufacturing sectors through robotization.[d]

However, while the greater use of robots in manufacturing production can compensate for the shrinking labour force and keep wage increases under control, with a view to smoothing the shift towards a new growth strategy, such rebalancing will also need to ensure the availability of a digitally skilled labour force and to prevent any balance-of-payments problems that could arise from expanding imports of machinery and technology-intensive intermediate inputs in the face of declining export revenues. From this perspective, attaining the policy targets of the Made in China 2025 initiative related to human capital and the domestic production of robots, as well as other high-end machinery, appears to be critical.[e]

a The "Made in China 2025" initiative is paired with the "Internet Plus" initiative, launched in July 2015, whose objective is to integrate mobile Internet, cloud computing, Big Data and the Internet of Things with modern manufacturing, to enhance the development of a wide array of services activities, and to increase the presence of domestic Internet-based companies in international markets. For further discussion, see the initiatives' websites, available at: http://english.gov.cn/2016special/madeinchina2025/ and http://english.gov.cn/2016special/internetplus/ as well as, for example, Wübbeke et al., 2016; and European Chamber of Commerce in China, 2017.

b See: http://english.gov.cn/state_council/ministries/2016/04/27/content_281475336534830.htm.

c See Direct China Chamber of Commerce, China industrial robot industry report and forecast 2016–2019, 15 July 2016; available at: https://www.dccchina.org/2016/07/china-industrial-robot-industry-report-and-forecast-2016-2019/.

d For this argumentation see, for example, Xinhua, " 'Made in China 2025' plan unveiled to boost manufacturing", 19 May 2015; available at: http://news.xinhuanet.com/english/2015-05/19/c_134252230.htm.

e The significant progress in innovation made by China in these areas is documented in, for example, Wübbeke et al., 2016; and, with a focus on robots, WIPO, 2015.

Germany, much of this was due to increased exports, as automotive and electronics exports from Mexico increased rapidly, while its exports of textiles and apparel declined between 2011 and 2015 (table 3.4).

As expected, unit labour costs declined faster on average in activities relying more on robotic automation than in industries with low robot density. As a result, such automation mostly rewarded capital and contributed to the downward trend in labour income share in Mexico, which declined by about 10 percentage points during the period 1995–2014 (ILO and OECD, 2015). Moreover, real wages in the highly automated automotive sector dropped by 1.6 per cent between 2011 and 2015, while real wages expanded by 1.5 per cent in manufacturing as a whole (table 3.4). This experience suggests that the overall distributional impact of robots may well be adverse.

TABLE 3.4 Germany and Mexico: Sectoral robot use and developments in output, employment, wages and trade, selected years

Country and sector	Robot density (Unit of robots per 10,000 employees)		Expansion of robot use	Change in output	Change in output per employee	Change in employ-ment	Change in real wages per employee	Change in unit labour costs	Change in exports	Change in trade surplus (or deficit)	Trade surplus (or trade deficit) (Percentage shares of GDP)	
	Initial period	*Final period*	*(Per cent)*								*Initial period*	*Final period*
Germany												
Total Manufacturing	**181.6**	**209.3**	**9.8**	**5.1**	**1.7**	**3.3**	**5.1**	**3.4**	**1.0**	**-9.2**	**11.3**	**10.7**
Food, beverages and tobacco	46.4	72.4	11.1	-1.5	-5.5	4.2	4.4	10.5	24.8	-34.8	-0.2	-0.2
Textiles, apparel and allied products	9.3	16.7	13.0	-11.4	2.1	-13.2	9.2	7.0	-5.7	53.1	-0.3	-0.2
Wood products except furniture	212.7	62.6	4.2	-3.4	-4.5	-7.7	0.3	5.0	-20.9	-90.2	0.0	0.0
Pharmaceuticals and cosmetics	54.6	168.7	14.2	13.7	1.4	12.1	6.2	4.7	32.8	71.4	0.6	1.0
Rubber and plastics products	143.4	400.6	13.0	6.8	0.2	6.6	3.4	3.2	-4.1	-28.8	0.8	0.6
Basic metals	96.1	87.3	8.1	-8.0	-8.2	0.2	1.7	10.8	-25.9	-26.4	-0.4	-0.3
Metal products, except machinery and equipment	63.4	129.3	13.3	0.7	-2.7	3.5	2.5	5.3	-18.7	-31.9	0.6	0.4
Machinery and equipment	29.5	75.2	13.0	-6.0	-15.2	10.9	3.2	21.8	-4.4	-9.8	3.5	3.3
Electrical/electronics	92.9	97.8	9.6	23.2	19.2	3.3	4.6	-12.3	-10.2	-153.3	0.4	-0.2
Motor vehicles, trailers and semi-trailers	944.7	1067.2	9.7	22.7	17.1	4.8	4.8	-10.6	8.1	7.1	3.8	4.3
Other transport equipment	61.1	53.3	8.7	39.1	23.2	12.9	18.2	-4.0	51.3	155.2	0.3	0.7
Mexico												
Total Manufacturing	**6.0**	**41.1**	**40.3**	**12.5**	**2.1**	**10.2**	**1.5**	**-0.7**	**26.2**	***-48.1***	**-1.8**	**-0.7**
Food, beverages and tobacco	0.1	2.8	39.3	6.8	4.6	2.1	2.7	-1.8	22.0	280.6	0.1	0.5
Textiles, apparel and allied products	0.0	0.0	n.a.	7.2	10.3	-2.8	3.1	-6.5	4.0	*79.0*	-0.2	-0.3
Wood products including furniture	0.0	1.1	87.5	7.8	3.9	3.7	3.1	-0.7	55.8	74.4	0.2	0.3
Paper and paper products	0.0	1.5	83.3	6.7	9.4	-2.5	4.3	-4.7	23.6	*6.2*	-0.3	-0.3
Pharmaceuticals and cosmetics	0.1	6.5	30.9	-3.5	1.1	-4.5	-7.1	-8.1	11.7	*21.5*	-0.2	-0.3
Rubber and plastic products	9.5	68.4	38.7	16.7	8.0	7.9	5.1	-2.7	28.4	*18.1*	-1.3	-1.5
Basic metals	1.2	16.4	41.9	11.0	0.8	10.1	4.4	3.5	-30.7	-74.6	0.3	0.1
Metal products, except machinery and equipment	1.4	5.7	41.5	11.7	9.7	1.8	1.7	-7.3	1.6	*45.9*	-0.7	-1.1
Machinery and equipment	4.1	39.1	33.3	7.5	-8.9	18.0	0.2	10.0	28.2	*35.6*	-1.1	-1.5
Electrical/electronics	0.5	8.5	34.1	19.3	14.2	4.5	3.2	-9.6	15.0	96.7	0.2	0.4
Automotive	29.5	153.5	41.5	42.7	-1.3	44.6	-1.6	-0.3	43.8	54.5	2.9	4.6
Motor vehicles, engines and bodies	121.4	513.1	39.8	39.9	4.2	34.3	n.a	n.a.	41.7	45.8	3.0	4.5
Automotive parts	15.6	103.5	42.7	46.3	0.1	46.1	n.a	n.a.	49.4	*-288.3*	-0.1	0.1
Other vehicles	16.5	12.4	20.7	86.8	21.7	53.5	n.a	n.a.	129.6	380.4	0.1	0.3

Source: UNCTAD secretariat calculations, based on National Institute of Statistics and Geography (INEGI), the Conference Board, and the IFR database.

Note: The time period depends on data availability and is 2007–2015 for Germany, and 2011–2015 for Mexico. Expansion of automation reflects the percentage change in the ratio of the average annual robot installation and the average robot stock over the sample period. Country-specific sectoral disaggregation depends on data availability. Robot data for wood and wood products in Germany include furniture. Sectoral breakdowns of wage and unit-labour cost data for Mexico are not fully comparable to those of the other data for Mexico: in particular, real wage and unit-labour costs data for "pharmaceuticals and cosmetics" refer to all chemical products and those for "automotive" refer to "transport equipment" and therefore also include "other vehicles". Trade data for aggregate manufacturing refer only to those sectors that are defined as manufacturing in trade statistics and therefore draw on fewer sectors than the other data regarding total manufacturing.

E. Conclusions

Despite substantial cross-country variation in the employment and income effects of robots, most existing studies overestimate the potential adverse effects. Job displacements are likely to occur only gradually, as what is technically feasible is not automatically economically feasible. Among jobs with identical displacement risk in technical terms, those at higher wage levels are exposed more to robot-based displacement for economic reasons. Such jobs are prevalent in more skill-intensive manufacturing sectors and in economies at a relatively mature stage of industrialization, rather than in labour-intensive manufacturing sectors and countries at an early stage of industrialization. And just as in past technological waves, digitization may create new products and sectors with new employment and income opportunities, even though there is little evidence that would point to digital technologies having already created large numbers of new jobs (e.g. Berger and Frey, 2016).

The creation of new employment and income opportunities that could compensate for adverse aggregate effects from robots, including by boosting employment where robots and workers are complementary, would be greatly facilitated by stable but expansionary global economic conditions, and by expansionary domestic macroeconomic policies. The associated policy shifts, which could drive sustained productive investment and support broad-based global income growth, are discussed in chapter VII of this *Report*. The continued absence of such shifts will tend to depress investment growth and hamper the unfolding of the job creation potential of the digital revolution. As a result, robotics will tend to further hold back aggregate demand growth by shifting employment away from technologically dynamic sectors, depressing productivity and real wage growth in relatively stagnant activities and "refuge sectors", and thereby reducing inclusiveness.

While much of the aggregate effect of robots remains uncertain and determined by macroeconomic forces, robot use does affect what jobs are available and where and by whom they will be done. Robots displace routine tasks that are usually done by workers on the middle rungs of the pay scale. The country-specific patterns of robot use indicate that industrial robots are sharpening the tendency towards concentration of manufacturing activities in a small group of countries. This concentration tends to harm inclusiveness at the international level and, given current global demand conditions, poses significant challenges for developing countries to achieve structural transformation towards well-paying jobs in manufacturing. In this sense, robotics could make it more difficult to pursue economic development on the basis of traditional industrialization strategies and achieve the 2030 Agenda for Sustainable Development.

Effects on inclusiveness at the national level depend on a range of country-specific conditions. These include a country's stage of industrialization and its position in the international division of labour. Sector-specific patterns of robot use indicate that engaging in the early stages of industrialization has largely remained unaffected at present, also because there is little evidence for reshoring of labour-intensive manufacturing tasks back to developed countries. It must be borne in mind, however, that robots are just one form of automation and that the early stages of industrialization may be exposed to job displacement through more traditional forms of automation, such as mechanization.

Another determinant is how countries use robots themselves, including with a view to avoiding what sometimes has been called the "middle-income trap" (*TDR 2016*). Robots can support the international competitiveness of firms that face rising labour compensation (such as from a shrinking labour force), uphold a large share of manufacturing in total output and facilitate structural transformation. However, this may result in a trade-off between creating large numbers of jobs with relatively little pay in labour-intensive sectors where robot-based automation is not (yet) economically feasible and fewer jobs with relatively higher pay for workers whose skills are complementary to robots.

Whether this dilemma can be avoided brings to the fore the impact of country-specific macroeconomic and trade policies as the third element that affects inclusiveness at the national level. Robot deployment in export-oriented manufacturing and compensating for potential adverse employment effects by increasing the scale of output appears to have helped some countries, such as Germany and Mexico, to smooth out adverse effects from robot use on inclusiveness. However, such a strategy also exports the negative employment and income effects to countries that import those goods.

To the extent that robot-based automation does actually reduce the number of manufacturing jobs globally, at least in the short run, countries that wish to maintain or build manufacturing employment will tend to compete in a shrinking global pool of manufacturing jobs. While great uncertainty remains as to how long that "short run" may last, the mere risk of protracted adverse effects on employment and inequality provides enough reason to consider how to minimize them. A more effective and sustainable strategy would emphasize the role of domestic macroeconomic policies, including public expenditure on activities (such as social spending) that improve the quality of life of citizens and generate large multiplier effects on output and employment, using the surpluses generated by increased productivity in the more dynamic sectors. This would be facilitated by coordination across countries, both developed and developing, to prevent beggar-thy-neighbour strategies from distorting such efforts.

Some have suggested that slowing down automation by taxing robots would give the economy more time to adjust and provide fiscal revenues to finance adjustment.[36] While this may well be the case, a robot tax presumes the possibility of avoiding tax havens where robots could be deployed tax-free. It also presumes the possibility of clearly separating what is produced by a worker from what is produced by a robot and the establishment of a fictitious income that a robot gets paid as a reference salary. Moreover, a robot tax may hamper the most beneficial uses of robots, i.e. those where workers and robots are complementary and those that could lead to the creation of digitization-based new products and new jobs.

Others have suggested a number of policies to promote a more even distribution of the benefits from increased robot use, based on the fear that robots will take over tasks with higher productivity and pay compared to the average tasks that will continue to be done by workers. If unchecked, these distributional effects from robotics would increase the share of income going to the owners of robots and the intellectual property that they incorporate, thereby exacerbating existing inequalities. Options to address these concerns include (i) raising wages through collective bargaining such that workers gain a higher share from productivity growth, and linking wage growth in technologically stagnant sectors to that in dynamic sectors in order to pull up aggregate investment and productivity growth; (ii) schemes where employee earnings depend on the firm's profitability so that a substantial part of citizens' income would come from capital ownership rather than from working (e.g. Freeman, 2015); (iii) increased use of inheritance and wealth taxes that would even out access to capital;[37] and (iv) the introduction of a universal basic income (or basic dividend), as discussed in chapter VII of this *Report*, part of whose rationale is based on the argument that the digital revolution requires a rethinking of welfare systems that have been built around labour and stable jobs in manufacturing.

Of particular importance for developing countries at early stages of development might be building a dense network of intra-sectoral and cross-sectoral linkages and complementarities (*TDR 2016*, chapter VI). This could further stem the risk of reshoring, even as the cost of owning and operating robots further declines and the scope of economically feasible automation gradually broadens, to also affect traditional, labour-intensive sectors. Doing so requires enhanced public investment in logistics and telecommunications infrastructure, as well as in supportive technological and innovation systems. Also needed are reliable supply networks that provide production inputs of the right quality at the right place and at the right time. Moreover, enhanced regional trade integration among developing countries could help them attain a market size that is sufficiently large for even affiliates of transnational corporations to forgo reshoring and maintain production in these countries. Developing countries could further reduce disruptions from automation by redesigning education systems to create the managerial and labour skills needed to operate new technologies and widely diffuse the benefits of their use, as well as to complement them.

Digitization could also open up new development opportunities. The development of collaborative robots, which do not replace human work but work alongside and increase the productivity of human labour, remains in its infancy. But so-called "cobots" could eventually be particularly beneficial for small enterprises, as they can be easily set up and do not require special system integrators and they can rapidly adapt to new processes and production run requirements. Combining robots and three-dimensional printing could create further new possibilities for small manufacturing enterprises to overcome size limits in production and to conduct business – both cross-border and national – on a much larger scale. The ensuing greater importance of final demand for locational decisions regarding the production of manufactures could significantly reduce the role of global value chains for goods. As a result, the production of manufactures could become less global and more regional. Future developments in robotics that would allow robots to be used profitably for small-scale production could eventually cause unit production cost variations among countries to become smaller than international transport and communications costs, making large-scale international merchandise trade less attractive and creating significant opportunities for localized manufacturing activities, including in developing countries.

At the same time, digitization may lead to a fragmentation of the global provision and international trade of services (see, for example, UNCTAD, 2014). While this could open up entirely new avenues for developing countries' development strategies, it is yet unclear whether digital-based services could actually provide similar employment, income and productivity gains as manufacturing has traditionally done.[38]

This discussion shows that disruptive technologies always bring a mix of benefits and risks. But whatever the impacts, the final outcomes for employment and inclusiveness are shaped by policies.

Notes

1 See, for example, Frey and Osborne, 2013; Galbraith, 2014; Ford, 2015; Chang et al., 2016; World Bank, 2016; McKinsey Global Institute, 2017.

2 For a definition of robots and robotic devices operating in both industrial and non-industrial environments, see https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-2:v1:en.

3 For discussion of digital development in agriculture and services, see United Nations, 2016.

4 For some initial discussion of this issue, see also UNCTAD, 2016a and 2016b.

5 Robot categories outside the industrial sector include service robots for professional use that are deployed in a wide range of uses, such as agriculture, professional cleaning, construction, logistics, medicine and defence, but the number of such units sold in 2015 was only about one sixth of that of industrial robots (International Federation of Robotics (IFR), 2016b). Service robots for domestic/household tasks and entertainment and leisure robots are sold in very large numbers but are of little relevance to the present discussion.

6 Sustainable Development Goal 9 aims to "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" and target 9.2 to "Promote inclusive and sustainable industrialization and, by 2030, significantly raise industry's share of employment and gross domestic product, in line with national circumstances, and double its share in least developed countries". Other areas of the digital revolution have been discussed in detail in UNCTAD's *Technology and Innovation and Information Technology Reports*, as well as United Nations, 2016. For a discussion of investment-related issues in the digital revolution, see UNCTAD, 2017.

7 To understand the difference between jobs and tasks, as well as the concept of "occupations" used further below, it may be useful to recall that the ILO (2008: 11) defines a job as "a set of tasks and duties, performed, or meant to be performed, by one person, including for an employer or in self-employment" and an occupation as "a set of jobs whose main tasks and duties are characterized by a high degree of similarity".

8 The definition of different occupations results from judgements by labour experts that assign scores to different indicators that supposedly characterize these occupations. The mapping of tasks into occupations merges job task requirements from the United States Department of Labor's Dictionary of Occupational Titles to their corresponding Census occupation classifications to measure routine, abstract and manual task content by occupations (Autor and Dorn, 2013). While it is not immediately clear to what extent such a mapping based on the United States labour market is applicable to other, in particular developing, countries, these countries do not have the data required for this mapping. Contrary to the calculation of the routine-task intensity index based on responses from individual workers on the actual nature of their daily work, which is used below, this methodology does not allow for sector-specific disaggregation of routine-task intensity.

9 Two other groups of studies look at automation of occupations. One is more judgemental, views occupations rather than tasks as being threatened by automation, and arrives at alarming estimates, such as that almost half of all jobs in the United States are threatened by automation (Frey and Osborne, 2013). The other uses workers' reports on the tasks involved in their jobs from the Organisation for Economic Co-operation and Development's (OECD) Programme for the International Assessment of Adult Competencies (PIAAC) to map tasks to occupations. It emphasizes that occupations themselves are particular combinations of tasks and that many

occupations change when some of their associated tasks become automatable. As a result, relatively few occupations can be automated entirely, and jobs will be altered rather than displaced completely (Arntz et al., 2016). But contrary to Autor and Dorn (2013), these two studies do not map tasks and occupations into economic sectors.

10 This observation is often referred to as "Moore's law". While there is agreement that the price of robots has significantly declined, this will only have benefited those firms that have actually used robots. Such firm-specific factors have been discussed, for example, in the "superstar firm" literature (e.g. Autor et al., 2017) that sees the productivity performance of a sector, or even an entire economy, driven by a few firms on which sales are concentrated and which reinvest ensuing larger profits in production. This topic is beyond the scope of this chapter, not least because of the lack of firm-specific data on robot use. But such firm-specific effects may explain the apparent paradox of rapid robot use being accompanied by a deceleration of economy-wide productivity growth in many developed countries, as recently argued, for example by Haldane (2017). Such firm-specific effects may also reinforce the persistence and simultaneous presence of very different technological stages within economic sectors, and even firms, that can be widely observed across developing countries.

11 Labour compensation is also a source of income and, hence, an element of aggregate demand. This means that a decline in labour compensation will reduce demand for the goods and services produced by robots and, thus, slow down investment in automation.

12 The routine-task intensity index used here is based on data for 2011–2012 from the OECD's Programme for the International Assessment of Adult Competencies (PIAAC). The data reflect answers from 105,526 individuals from the following 20 OECD member states that participate in PIAAC and report sectorally disaggregated data: Austria, Belgium, Canada, Czechia, Denmark, Estonia, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Poland, Republic of Korea, Slovakia, Spain, Sweden, United Kingdom and United States. For further discussion of this index, see Marcolin et al., 2016.

13 Figure 3.1 indicates proximate cross-sectoral relationships between technical and economic feasibility of routine task automation, and does not reflect numerically precise estimations.

14 For recent detailed discussion of long-term industrialization experiences, see also Felipe et al., 2015; Haraguchi et al., 2017; and Wood, 2017.

15 It should be noted that the shares of world manufacturing value added accounted for by different country groups presented here significantly deviate from those reported in UNIDO's *Yearbooks of Industrial Statistics*. This is due to differences in group composition. While the table follows the standard classification of country groups used by the United Nations, UNIDO also considers a number of, according to the United Nations' classification, developing countries, as industrialized economies, including some countries in West Asia and some East Asian economies (for further discussion of the UNIDO country groups, see *Country Grouping in UNIDO Statistics* Working Paper 01/2013, available at: https://www.unido.org/fileadmin/user_media/Services/PSD/Country_Grouping_in_UNIDO_Statistics_2013.pdf).

16 This is also why the experience of Mexico may be best described as "stalled industrialization" (see *TDR 2016*).

17 One explanation for this concentration may be that larger size allows for economies of scale and higher income for a higher income elasticity of demand for manufactures, so that both these elements tend to increase the share of manufacturing in a country's gross domestic product (GDP).

18 It should be noted that all comprehensive data sets on employment are afflicted by large gaps and inconsistencies in the country and year coverage of primary sources, and are therefore necessarily based on adjustment and estimation to some extent. Differences across such databases are particularly large for China. See Wood (2017: data appendix pp. 11–12) for a discussion of this issue and what choices underlie the data reported for China in table 3.2. The discrepancies between the data reported in table 3.2 here and those in table 3.2 in *TDR 2016* are caused by the use of different databases, where the database used in this *Report* has the advantage of providing more up-to-date data as required, for example, for the calculation of the various per-employee measures used later in this chapter.

19 One explanation for this is these countries' increased specialization in less labour-intensive manufacturing (see, for example, Wood, 2017) and in the case of the United States a very strong focus on the computer and electronics industry (Baily and Bosworth, 2014).

20 One reason for this would be path-dependent technological capability, i.e. acquiring the digital capabilities required for robot use may be easier for those who already possess well-developed technological capabilities.

21 The UNCTAD secretariat is grateful to the International Federation of Robotics (IFR) for granting access to its database free of charge.

22 It is worth noting that not all countries at a mature stage of industrialization have shown rapid increases in robot use, as the data for France, Italy and the United Kingdom in table 3.3 indicate.

23 The number for robot density in China is fraught with significant uncertainty. The IFR (2016a) reports a robot density of 49 for 2015, while Wübbeke et al. (2016), report for the same year a number of 19, explaining the difference by the inclusion of migrant

workers. The figure, which reports data for 2014, reflects a still lower number of about 10 robots per 10,000 employees, based on calculations with employment data from Wood (2017), whose data appendix (available at: https://www.wider.unu.edu/sites/default/files/Publications/Working-paper/Wood-data-appendix.pdf) details the reasons for uncertainty in employment data. It should also be noted that the IFR (2016a) reports a robot density of only 36 robots per 10,000 employees for China in 2014, i.e. the year to which figure 3.5 refers.

24 The evidence in figure 3.6 is only illustrative and should not be taken as numerically exact. This holds particularly for the location of the two bubbles for electronics and electrical equipment and for rubber, plastic and chemical products for which robot and labour compensation data need to be aggregated to match the level of aggregation of the routine-task intensity index. Data for China are not included in this figure because the country does not participate in the OECD's PIAAC and because the Conference Board does not publish sector-specific compensation data for China. However, this is unlikely to bias the results shown in the figure, given that the sectoral distribution of the stock of industrial robots in China closely mirrors that of the country sample used for the calculations. According to data from IFR (2016a), almost half of the stock of robots in China is in the automotive sector with electronics and electrical equipment and rubber, plastic and chemical products accounting for the bulk of the remainder. The textiles, apparel and leather sector accounts for only about 1 per cent of the stock of robots in manufacturing in China.

25 For discussion of this special role of manufacturing see *TDR 2014* and *TDR 2016*.

26 Offshoring tends to increase productivity in developed country firms through two additional channels. One is through imports of cheaper and more varied intermediate inputs from low-wage locations that reduce production costs. The other is through offshoring of the less sophisticated and less productive tasks and specialization in the more sophisticated and more productive tasks, increasing firms' aggregate productivity in the process (see, for example, Becker and Muendler, 2015).

27 This includes both workers in manufacturing global value chains (GVCs) actually employed in the manufacturing sector and those employed in non-manufacturing sectors but delivering intermediate goods and services for the manufacturing GVCs. According to Timmer et al. (2015), the share between these two types of workers is about half with that of the latter growing. Next to the United Kingdom, the United States was also the only country in the sample of 19 developed and developing countries that lost manufacturing GVC-related jobs also in agriculture and services.

28 Arguments on the erosion of developing countries' cost advantage may be based, on the one hand, on firms finding it difficult to assure and maintain high quality levels, especially in the face of risks from long value chains in terms of supply disruptions and, on the other hand, increasing wages especially in China, where it is estimated that labour compensation in manufacturing, measured in dollar, increased almost seven-fold between 2002 and 2013 (Conference Board, 2016). While data for China and the United States are not fully comparable it is, nonetheless, interesting to note that over the same period, labour compensation in manufacturing in the United States increased by about one third. A third possible reason for eroding costs competitiveness is that lead firms in buyer-driven value chains may feel the need to incur substantial costs to ensure decent working conditions in their offshore supply firms in order to avoid potential serious damage to the reputation of their brand.

29 Some of this evidence relates to choices by United States firms to invest in the domestic economy rather than in developing countries, as provided for example by the Reshoring Institute (https://www.reshoringinstitute.org/). Locational decisions by United States firms were probably also affected by expectations of the Trans-Pacific Partnership to enter into force, whereby lower trade costs would have further weakened the case for reshoring production from countries on the Pacific Rim. There is also evidence on reshoring to Germany (http://www.economist.com/news/business/21714394-making-trainers-robots-and-3d-printers-adidass-high-tech-factory-brings-production-back) even though such episodes are unlikely to involve reshoring of mass production but to relate more to the creation of new production lines focussed on the personalization of goods for high-income consumers.

30 According to Verdoorn's law, there is a long-run positive relationship between output growth and productivity growth in manufacturing as a result of increasing returns stemming from learning-by-doing effects and market expansion, such as from increased exports.

31 It may be argued that Autor et al. (2016) underestimate the sizeable role that public investment has played in the recent innovation experience of the United States (*TDR 2014*) and that reshoring manufacturing activities attempts to reinforce and supplement the effectiveness of such public investment by a greater involvement of the private sector. Bloom et al. (2016) find a positive impact of import competition from China, as well as from other developing countries, on innovation undertaken by firms in 12 European countries from 1996 to 2007. One reason for the different outcomes for the United States and Europe may be that the shareholder paradigm as a mode of corporate governance, and

the associated greater use of profits for dividend payments rather than for reinvestment, plays a much larger role in the United States (see also *TDR 2012*: 91–92). But the greater export orientation of firms in Europe, and especially Germany, may also have allowed them to foster innovation through market expansion that spreads the fixed costs of investing in new technologies, as discussed in section D.

32 For example, Pisano and Shih (2012) argue that design cannot be separated from manufacturing in the high-end apparel industry because design/aesthetic innovation and product quality are affected by how a fabric is cut and sewn into shape. The value of co-locating design with manufacturing is therefore high.

33 The measure of the increase in robot use employed here is the average of annual robot installations divided by the average robot stock, both for the period 2005–2014, i.e. the period for which the IFR (2016a) indicates greatest data reliability. This indicator does not capture the depreciation of the operational stock of robots and therefore may overestimate the expansion of robots in countries where the level of automation was already high before 2005. However, using this indicator is preferable to using the rate of growth of the operational stock of robots. In many countries, the operational stock of robots in the initial period (2005) was close to zero and the resulting rate of growth from such a low base would be extremely large and arguably meaningless for international comparisons. Moreover, the bias in the selected indicator is small: according to the IFR (2016a), industrial robots operate for 12 years, so that robots purchased after 2005 were still in operation in 2014. Hence, the overestimation of the growth in robot use only affects the small group of countries that had a relatively large and old stock of robots in the initial period. While Japan would be the most important of these countries, the IFR uses country-specific data that allow for a more accurate reflection of this country's robot stocks (see IFR, 2016a: 21).

34 This is not shown in the figure 3.12 in order not to blur the picture.

35 Sectorial data on robot shipments to Mexico, collected from the IFR are only available for the period 2011–2015.

36 Deploying a robot tax was discussed, for example, in May 2016 in a draft report to the European Parliament; available at: http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML%2BCOMPARL%2BPE-582.443%2B01%2BDOC%2BPDF%2BV0//EN. Emphasizing how robots could boost inequality, the report (p. 10) proposed that there might be a "need to introduce corporate reporting requirements on the extent and proportion of the contribution of robotics and AI to the economic results of a company for the purpose of taxation and social security contributions". The public reaction to this proposal has been overwhelmingly negative, with the notable exception of Bill Gates, who endorsed it. See: https://qz.com/911968/bill-gates-the-robot-that-takes-your-job-should-pay-taxes/.

37 Branko Milanovic, "Why 20th century tools cannot be used to address 21st century income inequality?", 12 March 2017; available at: http://glineq.blogspot.ch/2017/03/why-20th-century-tools-cannot-be-used.html.

38 Ghani and O'Connell (2014) provide an optimistic assessment, with scepticism expressed by Dani Rodrik, "Are services the new manufactures?", *Project Syndicate*, 13 October 2014; available at: https://www.project-syndicate.org/commentary/are-services-the-new-manufactures-by-dani-rodrik-2014-10.

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