

# Robots and Industrialization: What Policies for Inclusive Growth?

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## **Abstract:**

*Job displacement from robots has often been overestimated by neglecting that what is technically feasible is not always also economically profitable. Robots are not yet suitable for low-wage, labour-intensive industries, leaving the door open to enter industrialization along traditional lines while complicating moves towards higher-wage manufacturing. However, the window of opportunity in labour-intensive industries will eventually close as the cost of robots declines further, making them spread to lower-wage manufacturing sectors and eventually to lower-income countries. In addition to building digital infrastructure and skills, industrial policy to build intra- and cross-sectoral forward and backward linkages could stem reshoring of labour-intensive manufacturing to developed countries. Regulatory policies that prevent the few countries and firms that produce robots, as well as those that own the intellectual property embodied in them, from taking most of the benefits from robotization will also be necessary.*

## **1. Introduction**

The nature of employment and income opportunities is a major determinant of inclusive growth, and technological change greatly affects these opportunities. Economic history suggests that technological breakthroughs 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 innovation offers novel ways of producing and consuming, and creates new profitable areas of economic activity, allowing workers to move to new, more technology-intensive and better-paid jobs (e.g. Mokyr *et al.*, 2015; Perez, 2016).

The most recent technological wave builds around the generation, processing and dissemination of data. Although the computer launched this new wave, subsequent technological developments have emerged from sizeable advances in computing power, increasingly sophisticated audiovisual sensors and artificial intelligence. These include the spread of intelligent robots, Big Data, 3-Dimensional (3D) printing, the Internet of Things and online sharing platforms. The combination of these different information and communication technologies (ICTs) makes up the digital revolution. Within this broader context, much attention has been given to robotics and its potential to boost automation and productivity, revolutionize production processes and eliminate jobs on a massive scale.

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 better sustained global economic expansion. However, if productivity growth is achieved on the back of automation that causes job displacement and wage erosion, the commitment to inclusive prosperity of this Agenda will be technologically subverted before it gets off the ground.

Whether or not the experience with past technological waves is a useful guide for the effects of digitization is open to question. Some 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. Moreover, robots are exponentially getting smarter and more autonomous. The greater scope of occupational applications of robots and their faster improvements may give the economy insufficient time to adapt and compensate for job displacement by creating new and better jobs (e.g. Ford, 2015).

Another concern relates to distributional impacts. A key element in the distribution of gains from technological change is the return provided to those controlling the knowledge and the associated

intangible capital. Hence, the benefits from digitization may flow to a small number of people at the top of the digital chain, often in highly confined geographical regions. Moreover, operating the new tools of automation will probably require only a small number of highly skilled workers, 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 up-skilling 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.

Most of the current debate on the economic impact of robots focuses on developed countries (e.g. Acemoglu and Restrepo, 2017), but robotics clearly also concerns developing countries. From a development perspective, the big question is whether robots will reduce the familiar benefits of industrialization as a development strategy. 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.

The next section discusses whether manufacturing remains a desirable development strategy in spite of recent experiences of premature de-industrialization in a range of developing countries. Section three provides evidence on robot use in manufacturing. Section four examines which manufacturing sectors and countries are most vulnerable to robot-based job displacement. Section five turns to national distributional aspects of robot use. Section six addresses policies that could make digital technologies support, rather than subvert, industrialization in developing countries. Section seven concludes.

## **2. Salient Feature of Recent Industrialization Experiences**

Standard measures of industrialization are the shares of manufacturing in value added and in employment. Output data measured in current prices (table 1, columns 2–4) show that the world as a whole slightly de-industrialized over the past two decades, mainly as a result of declines in developed countries and transition economies. 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 to 23 percent. Moreover, developing countries raised their share in world manufacturing value added by more than 25 percentage points (from 21 to 47 percent, at current prices), of which almost 20 points are accounted for by China.<sup>2</sup> This increase occurred despite a decline of the share of manufacturing in China's total value added which, nevertheless, continued to exceed the developing country average.

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<sup>2</sup> 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. The table follows the standard classification of country groups used by the United Nations. But UNIDO also considers a number of what are, 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 country grouping, see UNIDO Statistics Working Paper 01/2013, available at:

[https://www.unido.org/fileadmin/user\\_media/Services/PSD/Country\\_Grouping\\_in\\_UNIDO\\_Statistics\\_2013.pdf](https://www.unido.org/fileadmin/user_media/Services/PSD/Country_Grouping_in_UNIDO_Statistics_2013.pdf)).

Table 1: Manufacturing value added and employment, selected economies and groups, 2005 and 2014 shares and 1995–2004 changes

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Share in total value added					Share in total employment		
	Current prices			Constant prices (2005)		2005 (percent)	2014	Change 1995–2014 (percentage points)
	2005 (percent)	2014	Change 1995–2014 (percentage points)	2014 (percent)	Change 1995–2014 (percentage points)			
	World	16.9	16.5	-3.2	17.9	1.7	13.4	13.3
Developed economies	15.6	14.1	-5.2	15.2	-0.3	14.8	13.0	-5.1
Germany	22.4	22.6	-0.1	23.4	1.8	19.4	19.8	-2.7
Japan	19.9	19.0	-3.2	21.4	2.7	16.9	14.2	-6.3
United States	13.2	12.3	-4.8	12.7	0.0	10.4	8.8	-5.1
Developing economies	21.1	20.2	-1.2	23.5	4.7	13.0	13.3	0.8
Africa	11.7	10.4	-4.4	11.6	-1.1	6.3	6.9	1.0
Latin America and the Caribbean	17.2	13.5	-4.2	15.4	-2.2	13.0	13.0	-1.2
Mexico	17.3	17.7	-1.9	16.7	-0.1	16.6	15.6	-2.1
Asia	24.0	23.2	-1.3	27.1	6.7	14.2	14.7	1.3
China	32.3	28.3	-6.1	34.9	5.7	16.4	18.2	2.8
Republic of Korea	28.3	30.3	2.5	32.7	10.7	18.5	16.6	-7.0
Taiwan Province of China	30.5	30.0	1.0	38.2	12.4	27.5	27.4	1.2
Oceania	9.7	8.6	-1.0	8.4	-1.0	n.a.	n.a.	n.a.
Developing economies excl. China	18.1	15.7	-3.9	18.4	1.4	11.3	11.1	0.2
Transition economies	18.2	15.3	-5.9	16.7	-0.6	15.9	14.3	-4.3
<i>Memo item :</i>	Share in world manufacturing value added (percent)			Share in world manufacturing value added (percent)		Share in world manufacturing employment (percent)		
Developed economies	68.2	49.7	-27.0	55.9	-18.9	18.2	15.0	-8.8
Developing economies	29.6	47.4	26.0	42.0	18.8	76.4	80.3	11.2
Developing economies excl. China	19.9	23.4	6.3	22.8	5.0	43.9	45.8	8.4
Transition economies	2.2	2.8	1.0	2.1	0.1	5.4	4.7	-2.3

Source: Author's calculations, based on United Nations, Department of Economic and Social Affairs, National Accounts Main Aggregates database; Groningen Growth and Development Centre, GGDC 10-Sector database; Haraguchi *et al.*, 2017; and Wood, 2017.

Each of Africa and Latin America and the Caribbean registered significant declines in their already low share of manufactures in total value added. While manufacturing activities in these two groups of countries increased in absolute terms, the decline in manufacturing shares and, hence, de-industrialization in these regions, was accompanied by an increase in the share of output from agricultural, mining and, especially, services activities. These de-industrialization tendencies were, in some countries, due to relative price developments between manufacturing and other economic sectors, and in particular the decline in the global price of labor-intensive manufacturing relative to both skill-intensive manufactures and primary commodities (e.g. Fu *et al.*, 2012). However, premature de-industrialization also reflects a combination of unfavorable macroeconomic and institutional conditions, weakening production linkages within and across sectors, insufficient economies of scale, and unfavorable integration into global markets (UNCTAD, 2016).

Output data measured in constant prices (table 1, columns 5–6) indicate that the share of manufacturing in value added fell only slightly in developed countries and transition economies taken as groups; it remained stable in the United States and increased in Germany and Japan. And it rose substantially for developing countries in aggregate.<sup>3</sup> In Developing Asia, changes in this share were strongly positive, 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 (UNCTAD, 2017). Taken together, the fact that the share of manufacturing in value added strongly increased in Asian developing countries and that this increase was driven by China, Taiwan Province of China and the Republic of Korea indicates that, across developing countries, manufacturing became more concentrated in the larger and richer economies (see also Haraguchi *et al.*, 2017; and Wood, 2017).<sup>4</sup>

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 labor 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 slightly declined between 1995 and 2014 (table 1, columns 7–9), while over the same period that of output measured in constant prices somewhat increased.<sup>5</sup> However, this tendency is most evident for developed countries.<sup>6</sup> 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 even below 9 percent. Japan experienced an even larger decline than the United States, though its manufactured employment share remained significantly larger than that in the United States. By contrast, Germany recorded a decline in its manufactured employment share between 1995 and 2014, equivalent to only 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. Manufacturing employment became increasingly concentrated in larger and richer developing countries, though less so than manufacturing output. And once again China accounts for most of the increase. For both Africa and developing countries in Latin America and the Caribbean, the evidence for output indicates more de-industrialization than that for employment. Africa even registered an increase of manufacturing in total employment, albeit from comparatively low levels

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<sup>3</sup> The evidence here relates to the size of manufacturing value added in developing countries as a whole, rather than to evidence on a declining manufacturing share based on the average picture of taking each developing country on its own, i.e. the methodology usually associated with the premature de-industrialization argument. One explanation for this apparent inconsistency between time series evidence for individual countries and that for the world economy as a whole may be a movement over time of global manufacturing towards more populous but lower productivity countries that counteracted massive within-country productivity growth in manufacturing and reduced the average share of manufacturing in total employment that industrializing economies could achieve (Haraguchi, 2014; Felipe and Metha, 2016).

<sup>4</sup> 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 GDP.

<sup>5</sup> All comprehensive datasets 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 1. The discrepancies between the data reported here and those, for example, in Hallward-Driemeier and Nayyar (2018) are caused by the use of different databases. The database used here has the advantage of providing more up-to-date data, as required for the calculation of the various per-employee measures used later in this paper.

<sup>6</sup> One explanation for this is these countries' increased specialization in less labor-intensive manufacturing (Wood, 2017) and in the case of the United States a very strong focus on the computer and electronics industry (Baily and Bosworth, 2014).

and on the basis of a greater extent of estimations of the data. Nevertheless, this evidence is in line with recent findings that the reallocation of African labor from the primary to the manufacturing sector has been accompanied by a decline in labor productivity of manufacturing (Diao *et al.*, 2017), suggesting little technological dynamism in African manufacturing.

Taken together, while there is evidence for premature de-industrialization to occur in some developing countries, the relative size of manufacturing continues to be of crucial importance to an economy's catch-up potential.<sup>7</sup> Table 1 indicates that the declines of manufacturing shares of both output and employment that many countries have experienced have been associated with the increasing concentration of manufacturing activities in a few developing countries. Historic evidence shows that attaining a share of manufacturing above 18 percent 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 some developing economies in Asia, such as China, the Republic of Korea and Taiwan Province of China. To the extent that history is any guide, once these few successful countries reach a mature stage of industrialization and move to services, the other developing countries may industrialize more easily.<sup>8</sup>

The question is how robotics affects these developments. If robot use becomes concentrated in those countries where manufacturing also has become concentrated, associated improvements in labor productivity and international competitiveness would allow them to prevent a decline, or even achieve an increase, in their own manufacturing activities.<sup>9</sup> As a result, other countries will find it more difficult to move along the traditional path of industrialization.

### **3. Robot Deployment: Cross-country and Cross-sectoral Evidence**

A major area of interest in the discussion of the digital revolution has been the greater use of industrial robots in production. While robotics is part of a wider process of automation, 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). These characteristics also make industrial robots different from other forms of digital automation such as Computer Numerical Control systems. These systems 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 autonomy and dexterity of modern industrial robots. These characteristics and differences have attracted particular attention because of the dramatic changes that they are presumed to bring about, even though in many developing countries 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.

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<sup>7</sup> For recent detailed discussion of long-term industrialization experiences, see also Felipe *et al.*, 2015; Haraguchi *et al.*, 2017; Wood, 2017; and Hallward-Driemeier and Nayyar, 2018.

<sup>8</sup> While the size of this effect depends on how China's production and trade structures evolve, it may be relatively small. Empirical evidence suggests that, though not trivial, China's opening during the 1990s did not, on average, have a large adverse effect on the share of manufacturing in other developing countries' broad sectoral output and export structures (Hanson and Robertson, 2010; Wood and Mayer, 2011). This may mean that a reduced emphasis in China's growth strategy on labor-intensive manufactured exports might provide space for smaller and poorer countries to boost their growth through export-led manufacturing, but this will unlikely be a promising strategy for larger and richer developing countries, especially given the current low dynamism of developed countries' manufactured imports.

<sup>9</sup> One reason for this would be path-dependent technological capability, i.e. acquiring the digital capabilities required for robot use in manufacturing may be easier for those who already possess well-developed technological capabilities and manufacturing activities.

Currently, the global use of industrial robots remains quite small, at only around 1.8 million in 2016 (table 2). However, it has increased rapidly since 2010, and it is estimated that by 2020 over 3 million industrial robots will be at work (International Federation of Robotics, 2017). The share of developed countries in the global stock of operational industrial robots continues to decline, but in 2016 it still amounted to 55 percent, with just three countries – Germany, Japan and the United States – making up 40 percent. By contrast, the recent increase in industrial robot deployment has been the most rapid in developing countries. However, this too has been heavily concentrated in Asian economies, particularly China.

Table 2: Industrial robots: estimated annual installation and accumulated stock, selected economies and groups, 2010–2016<sup>a</sup>

	Annual installation							Stock of operational robots	Change in stock of operational robots
	2010	2011	2012	2013	2014	2015	2016	2016	2010–2016
	<i>('000 of units)</i>							<i>(percent)</i>	
World	120.6	166.0	159.3	178.1	220.6	253.7	294.3	1828.0	72.6
	<i>(percentage shares)</i>							<i>(percent)</i>	
Developed economies	56.6	56.4	58.9	52.0	46.3	45.2	43.1	55.1	20.6
France	1.7	1.8	1.9	1.2	1.3	1.2	1.4	1.8	-3.2
Germany	11.7	11.8	11.0	10.3	9.1	7.9	6.8	10.4	27.7
Italy	3.7	3.1	2.8	2.6	2.8	2.6	2.2	3.4	-0.5
Japan	18.2	16.8	18.0	14.1	13.3	13.8	13.1	15.7	-6.6
United Kingdom	0.7	0.9	1.8	1.4	0.9	0.6	0.6	1.0	36.6
United States	11.9 <sup>b</sup>	12.4	14.1	13.3	11.9	10.8	10.7	13.7 <sup>b</sup>	45.7 <sup>b</sup>
Developing economies	41.0	39.2	37.7	44.8	50.1	52.9	54.9	42.6	251.4
Africa	0.2	0.2	0.2	0.4	0.2	0.1	0.3	0.3	119.8
Latin America & Caribbean	1.4 <sup>b</sup>	2.3	2.5	2.5	1.9	2.8	2.6	1.9 <sup>b</sup>	220.2 <sup>b</sup>
Mexico	0.7 <sup>b</sup>	1.2	1.3	1.5	1.1	2.2	2.0	1.1 <sup>b</sup>	227.7 <sup>b</sup>
Asia	39.4	36.7	34.9	42.0	48.0	49.9	52.1	40.4	254.7
China	12.4	13.6	14.4	20.5	25.9	27.0	29.6	18.6	550.2
NIEs	22.9	18.5	15.1	15.9	14.9	19.0	17.5	17.2	n.a.
Republic of Korea	19.5	15.4	12.2	12.0	11.2	15.1	14.1	13.5	143.7
Taiwan Province of China	2.7	2.2	2.1	3.1	3.1	2.8	2.6	2.9	97.5
Developing economies excl. China	28.6	25.6	23.2	24.3	24.2	25.9	25.4	24.0	160.0
Developing economies excl. NIEs	17.9	20.1	22.0	28.1	34.6	33.2	37.4	25.4	n.a.
Transition economies	0.2	0.2	0.3	0.4	0.2	0.1	0.1	0.2	218.2
Other economies	2.2	4.2	3.1	2.8	3.4	1.8	1.9	2.1	n.a.

Source: Author's calculations, based on the International Federation of Robotics (IFR) database.

Note:

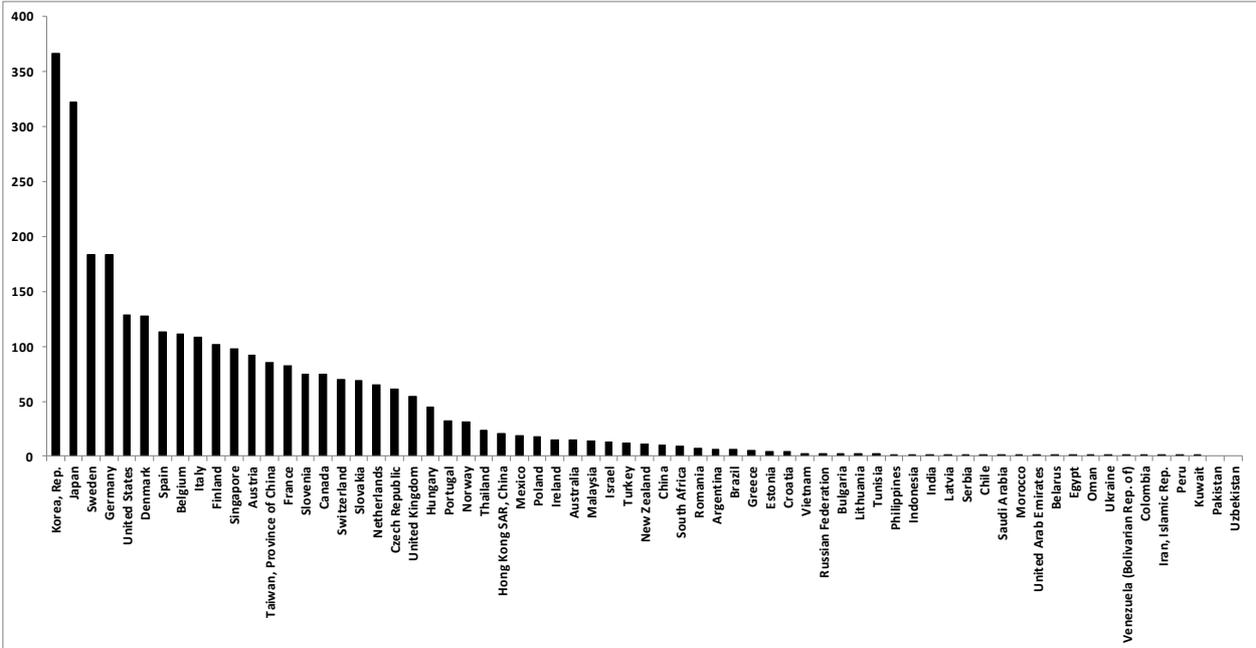
<sup>a</sup> The IFR calculates the operational stock of robots by accumulating annual deployments and assuming that robots operate for 12 years and are immediately withdrawn after 12 years, except for those countries, such as Japan, that undertake robot stock surveys or have their own calculation of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

<sup>b</sup> 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.

Between 2010 and 2016, the stock of industrial robots in China increased more than five-fold. The share in the global stock of industrial robots held by China exceeds that in Germany and the United States, and in 2016 surpassed the share of Japan. As a result, just three Asian countries – China, Japan and Republic of Korea – accounted for 48 percent of the estimated global stock of industrial robots in 2016. The group of developing countries excluding China and the Republic of Korea accounted for less than 11 percent of the global stock. There are hardly any robots in Africa; and 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.

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. Indeed, robot density, or 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 1). 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.<sup>10</sup>

Figure 1: Estimated robot density in manufacturing, 2014 (units of industrial robots per 10,000 employees)

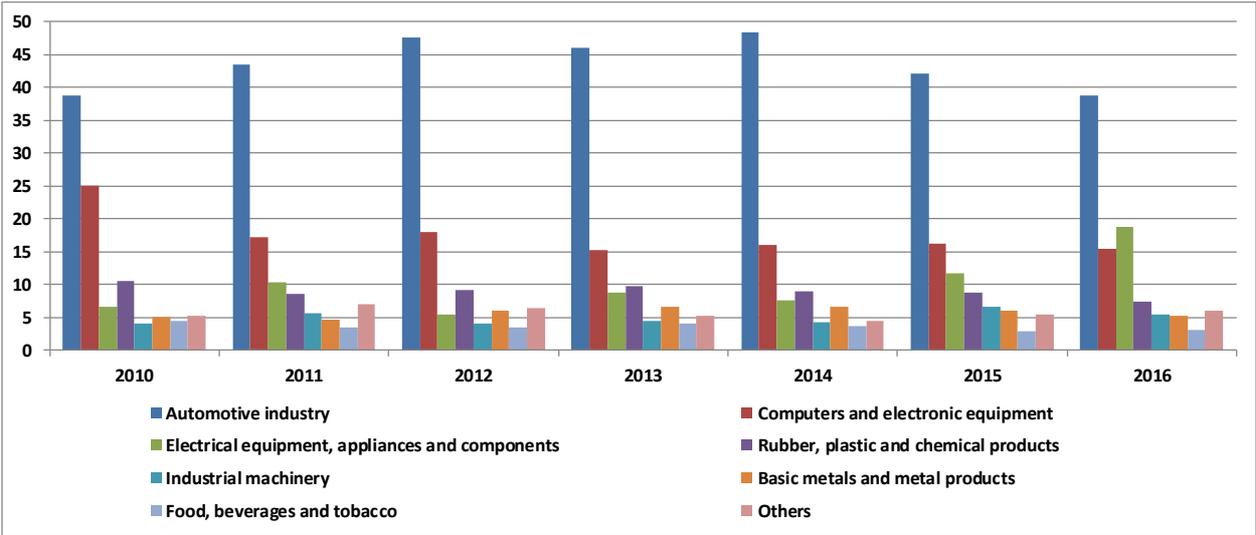


Source: Author’s calculations, based on the International Federation of Robotics database; and Wood, 2017.  
 Note: the figure shows data for all those 70 economies for which data are available

<sup>10</sup> The number for robot density in China is fraught with significant uncertainty. The International Federation of Robotics (IFR) reports a robot density of 49 for 2015, while Wübbeke et al. (2016) reports a robot density of 19 for the same year, explaining the difference by the inclusion of migrant workers. The figure, which shows data for 2014, the latest year for which comprehensive data for employment in manufacturing are available, reflects a number of only 10 robots per 10,000 employees. This number is based on calculations with employment data from Wood (2017), whose data appendix details the reasons for uncertainty in employment data. It should also be noted that, referring to the industrial sector as a whole, the IFR reports a robot density of only 36 robots per 10,000 employees for China in 2014, the year to which figure 1 refers.

The use of industrial robots in manufacturing is also heavily concentrated in just five sectors: the automotive industry accounted on average for about 43 percent of annual deployment between 2010 and 2016 (but with a decline in 2016 back to its level of 2010 of about 39 percent), followed by computers and electronic equipment (about 15 percent), electrical equipment, appliances and components (about 10 percent, but with an increase from about 12 percent in 2015 to almost 19 percent in 2016), followed by the group of rubber, plastic and chemical products, and by machinery (figure 2).

Figure 2: Industrial robots: global annual installment, by manufacturing sector, 2010–2016 (percentage shares of total industrial robots in manufacturing)



Source: Author’s calculations, based on the International Federation of Robotics database.

To sum up, industrial robot use in manufacturing has remained low. It has been highly concentrated in a few manufacturing sectors and is highest in economies where global manufacturing has become concentrated.

**4. Technical Feasibility and Economic Profitability of Robot-Based Automation**

As previously mentioned, industrial robots are machines that can be programmed to perform production-related tasks without the need of a human controller. This greater autonomy causes industrial robots to dramatically increase the scope for replacing human labor compared to conventional types of machines. Rapid technological change has halved the price of industrial robots between 1990 and 2005 (Graetz and Michaels, 2016), as also reflected, for example, in the reduction of the global price of capital goods relative to that of consumer goods by some 25 percent between 1975 and 2012 (e.g. Karabarbounis and Neiman, 2014). Most of this decline stems from the size of transistors shrinking so rapidly that everyone 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. 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).

Assessments of the employment impact of robots have generally used a task-based approach. This approach hypothesizes that a job is composed of different tasks, and that new technology does not always favor better-skilled workers but often complements workers in certain tasks of their job, while substituting

for them in others (e.g. Autor *et al.*, 2003). 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 labor in routine tasks. These are those that can be clearly defined and follow pre-specified patterns, so that they can be coded and translated into the software that drives robots. 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 often found in the services sector.

One way of operationalizing the task-based approach and determining the technical feasibility of automation is the calculation of routine-task intensity indices, which link routine tasks to occupations that workers perform on their jobs (e.g. Autor and Dorn, 2013; Marcolin *et al.*, 2016). The resulting indices indicate that routine-based tasks dominate in occupations that are typical for manufacturing. They also imply that, from a technical point of view, workers doing routine tasks in manufacturing are most at risk of robot-based automation.

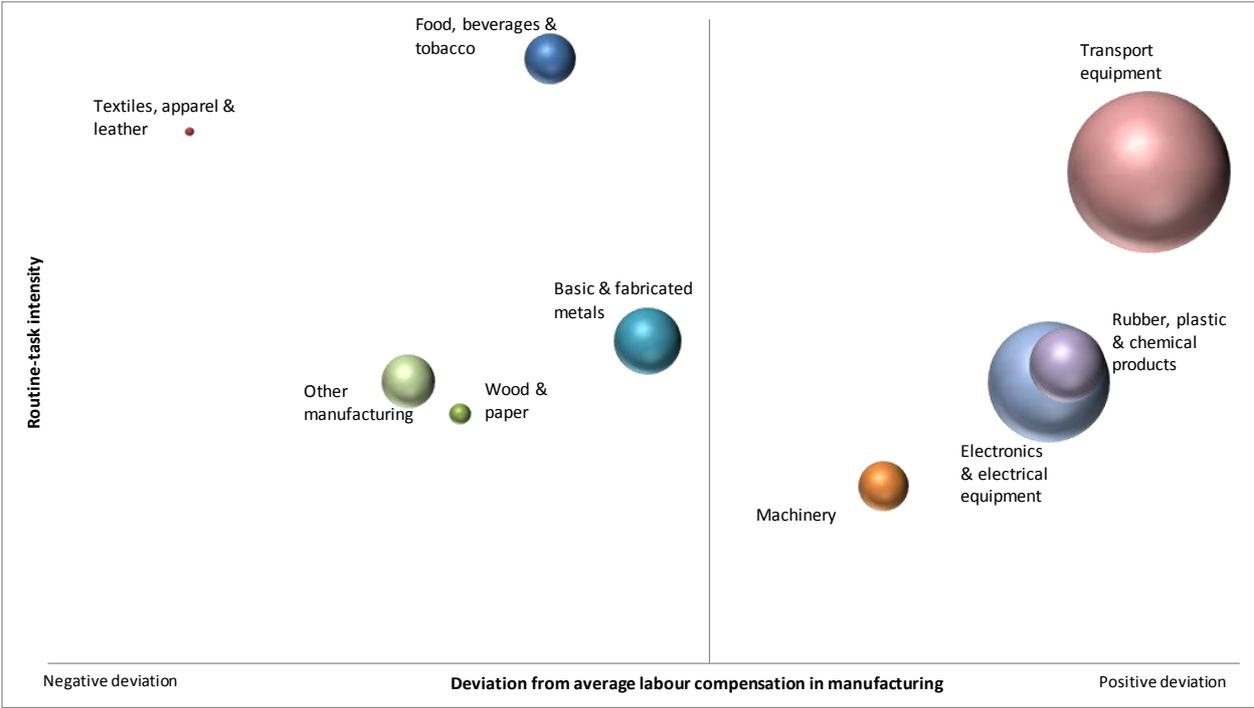
Studies indicating robots' dramatic job displacement potential (e.g. Frey *et al.*, 2016) generally emphasize this technical feasibility of workplace automation. But such assessments tend to overestimate the potential adverse effects of robot-based automation. This is because a substitution of labor by capital, including in the form of robots, that is technically feasible will occur only if it also provides economic benefits. This economic perspective suggests that the cost of automation must be compared with the cost of labor in routine tasks. The latter cost is determined by a range of factors, such as the cost of developing and deploying new capital equipment. However, it crucially depends on labor compensation which, as the prevalence of routine tasks, tends to vary across different economic sectors.

Figure 3 links robot use in manufacturing on the one hand, and technical feasibility and economic profitability of robot-based automation on the other. The vertical axis reflects the technical feasibility of robot-based automation, based on a routine-task-intensity index for specific manufacturing sectors (Marcolin *et al.*, 2016).<sup>11</sup> It suggests that the technical feasibility of job displacement in manufacturing is highest in food, beverages and tobacco, followed by the textiles, apparel and footwear sector. The horizontal axis reflects the economic profitability of robot-based automation in manufacturing, based on sector-specific labor compensation. It suggests that job displacement by robots in relatively skill-intensive and well-paying manufacturing, such as the automotive and electronics sectors, is more profitable than in relatively labor-intensive and low-paying sectors, such as apparel.

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<sup>11</sup> Figure 3 indicates proximate cross-sectoral relationships between technical and economic feasibility of routine task automation and does not reflect numerically precise estimations. 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 labor 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 for 2016 from the IFR-database, over 40 percent of the stock of robots in China's manufacturing sector 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 less than 1 percent of the stock of robots in manufacturing in China. 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, Czech Republic, 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.

Figure 3: Proximate relationship between technical feasibility and economic profitability of routine-task automation, by manufacturing sector



Source: Author’s calculations, based on Marcolin *et al.*, 2016; the Conference Board, International Labor Compensation Comparison database; and the International Federation of Robotics database.

Note: The axes have no scaling to underline the proximate nature of the relationship shown in the figure. Bubble size reflects the stock of industrial robots in 2016. All data are for a sample of 20 countries (see text note 11 for details) and refer to the latest available year. The routine task intensity index refers to 2011–2012. Labor compensation reflects sector-specific medians for the period 2008–2014. Calculating labor 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 labor compensation and stocks of robots, results in only marginal variation in the cross-sectoral relationship shown in the figure.

The sizes of the bubbles in figure 3 reflect the sectoral distribution of the global stock of operational industrial robots in 2016. The evidence shows that robots are concentrated in manufacturing sectors that are on the right-hand side of the figure, rather than at its top. 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 labor costs both increase. The figure also suggests that robot deployment has remained very limited in manufacturing sectors where labor 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.<sup>12</sup>

<sup>12</sup> It should be noted, however, that reduced robot adoption may also be related to technology issues of automation unrelated to workers’ tasks, such as the pliability of fabrics in the apparel sector and the need to insert small flexible parts into tightly packed consumer electronics (ILO, 2017).



however, that robot-based automation does not invalidate the traditional role of industrialization as a development strategy for lower-income countries. At least in the short run, cheap manufacturing and the associated exports will continue to play a crucial role in allowing developing countries to grow rapidly while creating jobs.

Yet, the dominance of robot use in sectors higher up on the skill and wage ladder implies greater difficulty for latecomers in attaining sectoral upgrading, and may limit their 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. Such potential adverse effects may be reinforced in the long run because the cost of robots will most likely decline further and make them spread to lower-wage manufacturing sectors, and eventually to lower-income countries as well.

## **5. Robot-Based Productivity and Inclusiveness Effects at a National Level**

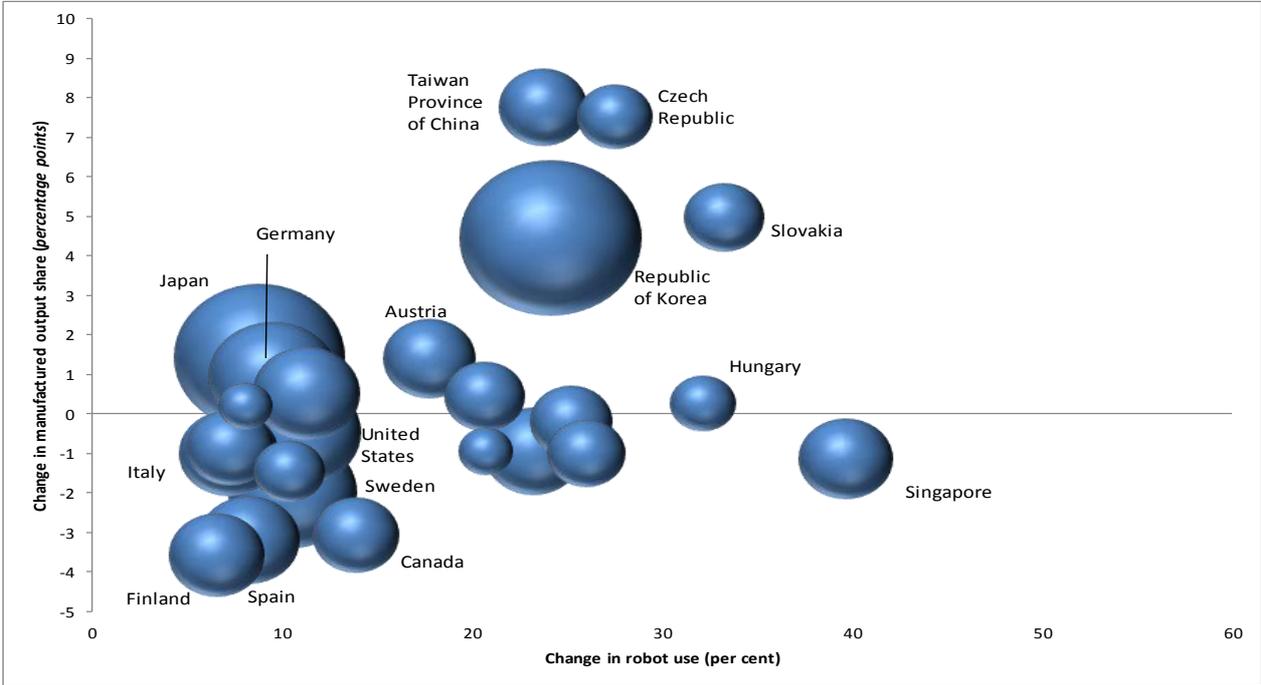
Cross-country evidence for the period 2010–2014 suggests a positive relationship between increased robot use and an increased share of manufacturing in total value added.<sup>13</sup> This relationship holds in particular for those economies where robot density is comparatively large (figure 5a). The evidence for any such relationship in economies with comparatively small robot density is somewhat less clear (figure 5b). However, it is worth noting that many countries where industrial robot use is low also experienced de-industrialization in terms of a shrinking share of manufacturing in total value added. Thus, figure 5 supports the finding in the previous section showing that robot use tends to foster a concentration of manufacturing activity in a small number of countries.

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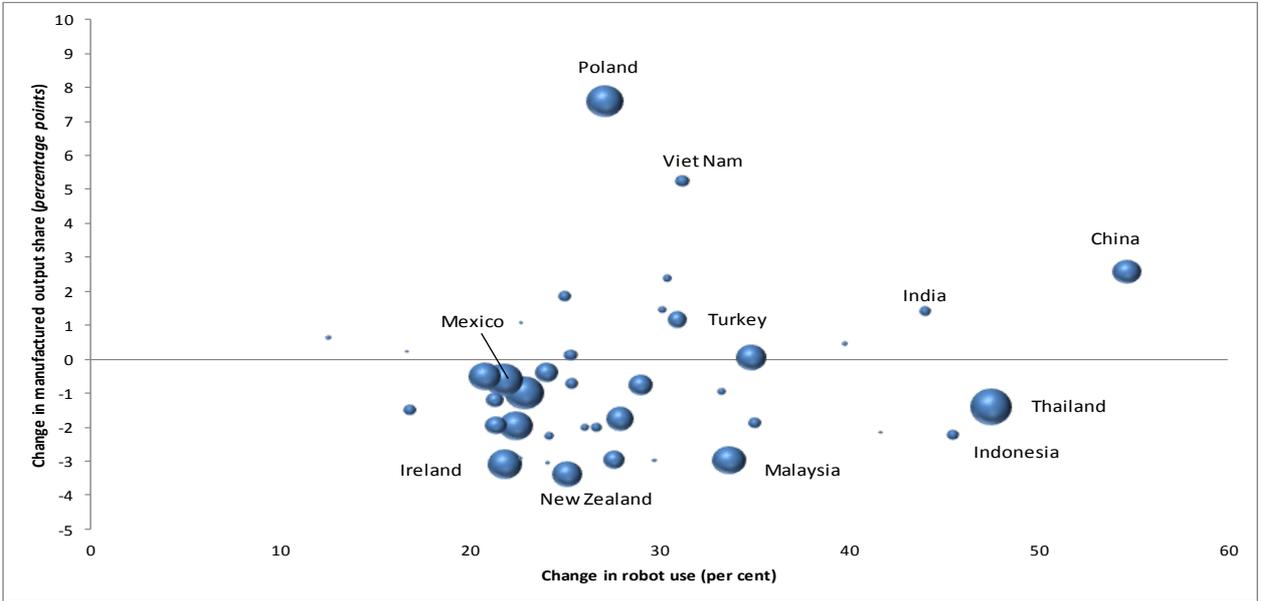
<sup>13</sup> The measure of the increase in robot use employed here is the average of annual robot installations divided by the average robot stock, both for the period 2005–2014, the period for which the IFR (2017) indicates greatest data reliability, and for which comprehensive employment data are available. 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 (2017), 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.

Figure 5: Robot use and manufactured output share, selected economies, change between 2005 and 2014

A. Economies with robot density exceeding 30 industrial robots per 10,000 employees



B. Economies with robot density below 30 industrial robots per 10,000 employees

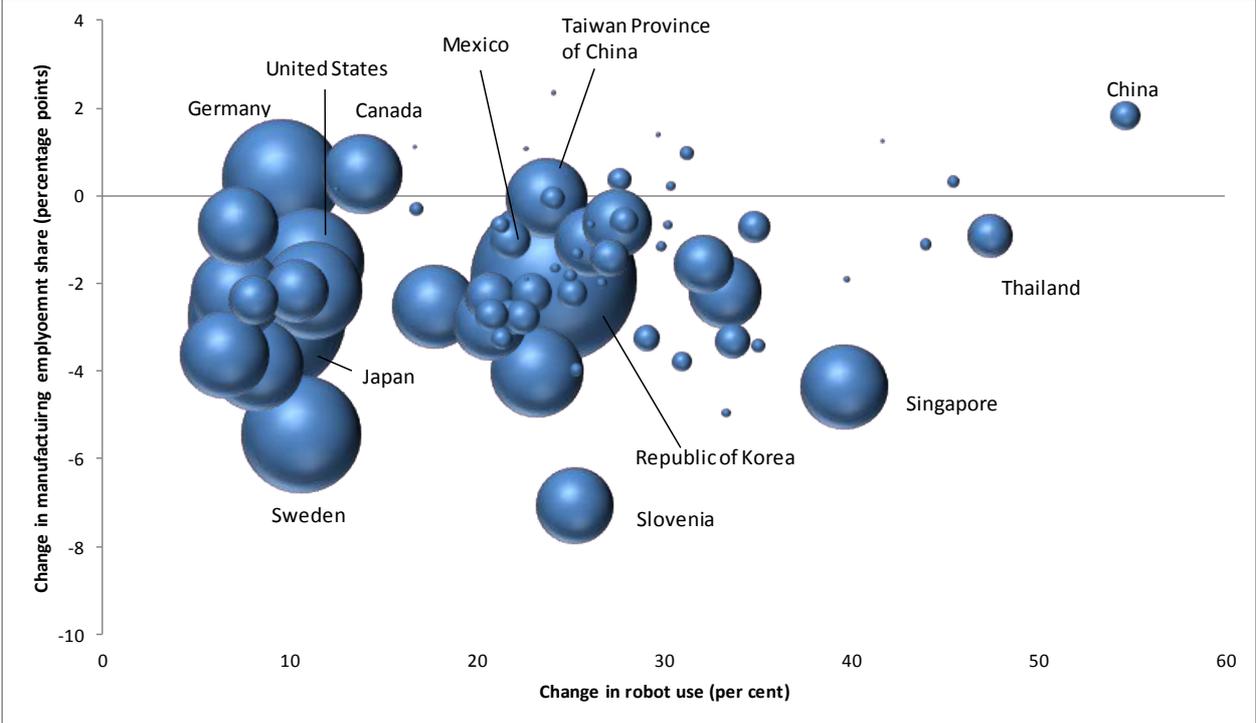


Source: Author’s calculations, based on the International federation of Robotics database; and Wood, 2017.

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 manufactured output share reflects the percentage point change in the share of manufacturing in total value added between 2005 and 2014. Bubble size reflects robot density in manufacturing in 2014. The figures include the 64 economies for which data are available, of which 24 economies in figure 5a and 40 economies in figure 5b.

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 6). Given the evidence of a positive relationship between robot use and labor productivity (UNCTAD 2017: figure 3.8) and considering that the very purpose of using robots is to automate certain tasks, this finding is not surprising.

Figure 6: Robot use and manufacturing employment share, selected economies, changes between 2005 and 2014



Source: See figure 5.

Note: Bubble size reflects robot density in manufacturing 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.

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 (UNCTAD 2017: 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 data are available, increased robot use was associated with real wage growth in all economies except Mexico, Portugal and Singapore, which recorded small declines (UNCTAD, 2017: figure 3.12). Growth of both real wages and robot use was particularly large in China (at roughly 150 percent and 55 percent, respectively).

Taken together, the country-specific evidence suggests great variation in the distributional impact of robot-based automation. Employment and wage effects appear to be conditioned by country-specific

circumstances, including institutional arrangements (such as workers' bargaining power), country-specific robotics initiatives and, probably most importantly, economic policies. This is because economic policies greatly affect the impact of automation on aggregate demand. If productivity gains 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. Robots boost companies' international cost competitiveness, which may in turn spur exports and thereby make other countries bear at least part of the adverse consequences from robot-based automation through reduced output and employment opportunities. Evidence for Germany and for Mexico's auto industry shows that these countries' increased use of robots has been accompanied by productivity and employment gains, but also by a growing export surplus in the most robot-intensive sectors (UNCTAD, 2017: table 3.4).

## 6. Policies for Inclusive Industrialization in the Digital Era

History suggests that the outcome of innovation is not an autonomous process but shaped by policies. This holds particularly true if technology waves are composed by a first phase of process innovation and job destruction and a second phase of product innovation and job creation, which together result in positive aggregate employment and income effects. From this perspective, the current digital wave may be in its job destruction phase but eventually create new employment and income opportunities from new products and economic sectors (e.g. Perez, 2016). Expansionary macroeconomic conditions at the global level are required for such positive longer-term dynamics to occur. However, policies that would support sustained high investment in the real economy are currently missing.<sup>14</sup>

But even if the current technology wave has no adverse effects on the aggregate number of jobs in the long run, it will affect production processes and business models and, therefore, the kind of jobs available and how and where they are done. This may be the case particularly for sectors where robot-based automation advances most and where large-scale application of other digital technologies, such as 3D-printing and new types of ITCs associated with the Internet of Things, including cloud computing and big-data analysis, is most rapid.

Given that the largest of these sectors, e.g. the automotive and the electronics sectors, are also those where value chains have played a key role, what the new digital technologies mean for the geographical location of manufacturing and associated industrialization policies may be illustrated on the basis of the so-called "smile curve." The smile curve distinguishes pre-production, production and post-production stages in value chains, where the high value-added pre- and post-production stages have typically been located in developed countries, while the labor-intensive production stages have concentrated in developing countries. Some observers expect the new digital technologies to make value chains move towards greater geographic clustering of the three stages (e.g. Sturgeon, 2017; Rehnberg and Ponte, 2017). From this perspective, an important policy question for developing countries is how to maximize the domestic share in the value added of the broader manufacturing process, i.e. across the three stages.

Regarding production, robots may mainly have two effects. First, countries that produce within already robotized value chains may need to robotize their production as well in order for their firms to remain

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<sup>14</sup> This perspective also raises doubts on the suggestion that slowing down automation by taxing robots would give the economy more time to adjust and provide fiscal revenues to finance adjustment. Indeed, 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 jobs.

competitive and their inputs to meet lead firms' standards. The relative high robot density of countries in Central Europe, such as the Czech Republic, Slovakia and Slovenia, which are closely integrated in value chains led by German automotive firms, and the related positive (negative) association between their change in robot use and their change in manufacturing output (employment), provides some supportive evidence (see figures 1, 5 and 6 above).

On the other hand, further evolution of robotics could also provide new employment opportunities for these countries. The development of collaborative robots, which do not replace human work but work alongside and increase the productivity of human labor, remains in its infancy. Yet, such so-called "cobots" could be particularly beneficial for small enterprises: they can be easily set up, do not require special system integrators and can rapidly be adapted to new processes and production run requirements. This could help domestic manufacturing enterprises, including in the automotive sector, to overcome size and quality limits in production and broaden the range of domestically sourced intermediate goods in the value chain.

Second, robot use in low-wage labor-intensive manufacturing has remained low. Yet, developing countries' employment and income opportunities in these sectors may be adversely affected by the re-shoring of manufacturing activities to developed countries. In developed countries, the combination of robotics with 3D-printing may spur re-shoring and reorganization of production processes. One rationale for re-shoring concerns the advantages of locating production geographically close to product design, as manufacturing competence is integral to innovation (e.g. Pisano and Shih, 2012).<sup>15</sup> From this perspective, re-shoring is mainly a means to stimulate innovation and product development by the relocation of production activities to areas where firms expect that links between production and research and development, and its positive impact on innovation, can be encouraged best.

There is yet only fragmented and anecdotal evidence of the significance of re-shoring.<sup>16</sup> Survey results and responses to firm-level questionnaires that aim to provide broader and more systematic evidence indicates that off-shoring continues, but also that some re-shoring has occurred at a slow pace and across all industrial sectors, albeit at different intensities and for different motives (e.g. De Backer *et al.*, 2016). One reason why the pace of re-shoring has remained slow may be tepid investment and sluggish aggregate demand in developed countries more generally.<sup>17</sup> Moreover, these countries lack the supplier networks that some developing countries have built to complement labor-intensive assembly activities. Yet, while labor-cost differentials remain a factor in firms' decisions of where to locate production, especially of goods with a high labor 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 labor-intensive manufactures destined for rapidly growing markets in large developing countries with domestic production linkages is unlikely to be re-shored. Building a dense network of intra- and cross-

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<sup>15</sup> 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.

<sup>16</sup> One of these anecdotes concerns developed countries' creation of robot- and 3D-printing based "speed factories" to produce foot- and leisure wear (e.g. <http://www.economist.com/news/business/21714394-making-trainers-robots-and-3d-printers-adidass-high-tech-factory-brings-production-back>). However, such episodes are unlikely to involve re-shoring of mass production, but to relate more to the creation of new production lines that focus on the personalization of goods for high-income consumers and would not be possible to produce with traditional manufacturing.

<sup>17</sup> While the political debate on re-shoring in developed countries is often cast in terms of "bringing jobs back", evidence shows that where re-shoring to developed countries has occurred, it has fallen short of such expected employment effects. Re-shoring 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 re-shored production will not be the same as those that have left.

sectoral forward and backward linkages and complementarities could further stem the risk of re-shoring, even as the cost of owning and operating robotics systems further declines and the scope of economically feasible automation gradually broadens to also affect traditional labor-intensive sectors such as garment-making.

New digital technologies also affect the pre-production stages. Digital design simulation reduces the number of work hours required to create new goods, as well as the expertise needed to design high quality goods. Such opportunities may be enhanced by using 3D-printing that facilitates rapid prototyping and the production of specialized machinery, with a view to further compressing the product development cycle of products that may subsequently be mass-produced with traditional technology and infrastructure (e.g. Sturgeon, 2017). The automobile sector provides examples of targeted innovation for less-demanding markets that complements ensuing traditional labor-based manufacturing production (e.g. Midler *et al.*, 2017). The use of digital technologies in the pre-production phase would most likely help compensate, at least in part, for the lack of skilled designers and an established machinery industry in developing countries. Evidence shows that robot density in countries such as India, Morocco, Romania and the Russian Federation has remained relatively low (figure 1), and that the number of robots in these countries' automobile sector has most likely remained much lower<sup>18</sup> than in the above mentioned Central European countries. This could indicate the co-existence of highly-robotized automobile production for developed country consumers and more traditional labor-based automobile production for developing country consumers that demand simpler and cheaper cars even if they are of lower quality.<sup>19</sup> Harnessing digital technologies for pre-production stages of automotive production, as well as in other sectors, could therefore provide significant opportunities for developing countries' manufacturing activities.

New digital technologies and associated digital capital will most likely increase the importance of the post-production stage within the manufacturing process. Digitized production tends to give high priority to product customization and lowest possible lead times, and to allow for end users to participate in product design and production. Accordingly, the use of ITCs associated with the Internet of Things – such as cloud computing and big-data analysis – to collect end-user data and analyze them for design and production decisions could provide new opportunities for developing countries where technical skills might be low, but knowledge of local market preferences is high. The ability to flexibly respond to domestic consumer demand may become particularly important for developing countries whose export opportunities have been severely dented by the declining dynamism of world trade, but whose domestic markets are relatively large.

More generally, new digital technologies provide increased possibilities for customization in production, the availability of real-time data on consumption behavior and its instant transmission through the Industrial Internet for design and production decisions. This would make value chains more demand driven and probably bring both pre-production and production stages closer to end markets. Ownership of and access to data on consumer preferences and behaviors, as well as data analysis skills, will be key determinants of the distribution of value added in such digital value chains.<sup>20</sup>

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<sup>18</sup> The IFR (2017) indicates that, in 2016, India's robot density in the automotive sector was only 79 units per 10,000 employees, compared to 420 in the Czech Republic, 707 in Slovakia and 851 in Slovenia. While no sector-specific data is available for Romania and the Russian Federation, it reports robot density for these countries in all of manufacturing as 15 and 3, respectively, in 2016. The IFR (2017) includes data for Morocco in aggregate numbers for Africa, with no indications of robot density.

<sup>19</sup> Verhoogen (2008) shows that such co-existence arose in Mexico's automotive sector in the mid-1990s.

<sup>20</sup> To the extent that knowledge of consumer preferences and behavior are intangibles in goods production that give rise to winner-take-all market structures, new products that meet consumer expectations even only slightly better than traditional goods can allow new producers to take over the entire market.

A range of policy measures could help developing countries play an important role in such future, more demand-driven value chains. The provision of hard and soft digital infrastructure (e.g. broadband internet connectivity, digitally skilled labor) is a basic requirement for people and enterprises to engage successfully in the digital economy. However, merely increasing connectivity might strengthen already more productive firms. Hence, appropriate competition and antitrust policies should accompany increased digital connectivity. Exploring what policies regarding standards, public participation in long-term finance, public procurement, bold demand policies, data localization etc. could maximize benefits for developing countries in the digital economy may also be necessary. It is also clear that developing countries can reap such benefits only if their consumers have the income required to turn their preferences into effective demand without recurring to debt. In this sense, there is a virtuous circle between the new digital technologies' greater emphasis on consumer demand and customized products, on the one hand, and greater involvement of developing countries in manufacturing processes that satisfy such demand on the other.<sup>21</sup>

International trade and investment agreements increasingly include rules regarding digitized economic activities. There remains wide variation in views as to the effects of adopting negotiated rules in this area. Adopting such rules at this stage may (i) prevent regulations from arising through practices and patterns of behavior that might be unduly shaped by firms which are further advanced in the digital economy; or, instead, (ii) be premature in this rapidly evolving area and unduly reduce policy space for digital industrial policies. Yet, both positions indicate that the existing institutional setup of international trade and investment relationships may be ill-equipped to deal with issues arising with new digital technologies.

Finally, 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, as well as those that own the intellectual property embodied in them, will benefit from robotics more than other countries and firms. The little evidence that is available (UNCTAD, 2017: 46) suggests strong geographic concentration of these returns – mainly in Japan, the Republic of Korea and Germany, as well as probably the United States for which, however, no specific data are available. A strong concentration of intellectual property rights in the knowledge that drives the digital revolution could cause extreme inequality at both national and international levels.

To contain this risk at the national level, all countries need appropriate regulatory frameworks to prevent a few from taking most of the benefits. Moreover, governments could acquire stakes in the commercialization of successful new technologies by establishing professionally managed public venture funds. These funds would take equity stakes in a large cross-section of new technologies, financed through bond issues in financial markets, and share profits with citizens in the form of a social innovation dividend (Rodrik, 2015). In this way, the fruits of high productivity growth from labor-displacing technological change could spread more widely and fuel aggregate demand for output from lower productivity sectors while increasing employment and average productivity.

## **7. Conclusions**

The job displacement effects of industrial robots have often been overestimated by neglecting that what is technically feasible is not always also economically profitable. Industrial robots are not yet suitable for low-

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<sup>21</sup> In light of the reduced dynamism of global trade and the ensuing more limited role that manufactured exports can play in developing countries' growth strategy, policies designed to boost domestic manufacturing activities, employment and incomes have acquired heightened importance particularly for large developing countries that try to maintain rapid economic growth, while alleviating the balance-of-payment constraint to growth and avoiding economic growth from relying on mounting debt (e.g. Mayer, 2017).

wage, labor-intensive industries, leaving the door open for developing countries to enter industrialization processes along traditional lines in lower-skill, lower-wage, labor-intensive manufacturing sectors, such as apparel and footwear.<sup>22</sup> Benefitting from the job creating potential of such activities may be of crucial importance, especially for the many populous poor developing countries. However, this window of opportunity will eventually close as the cost of robots declines further, making them spread to lower-wage manufacturing sectors and eventually to lower-income countries.

At the same time, other elements of the digital revolution – such as 3D-printing, digital design simulation, cloud computing and big data analysis – could empower developing countries to increase their benefits from value chains and advance their industrialization strategies. This means that to harness the opportunities from digital technologies, developing countries will need not only to provide appropriate hard and soft digital infrastructure, but also to adapt their industrial policies to the digital world. They must also address the entire manufacturing process by taking into account pre- and post-production processes in addition to the manufacturing production process itself.

Such broader industrialization policies will most likely be required also more generally for the new digital technologies to create new goods and economic sectors that would help absorb displaced workers. They also concern expansionary macroeconomic conditions at the global level that would support sustained high investment in the real economy. Such conditions are currently missing. This means that the novelty of the digital revolution does not lie in its greater scope and faster speed of automation alone, but also in its occurrence at a time of subdued macroeconomic dynamism that tends to hold back the investment needed for the new technologies to boost productivity, while creating new sectors and occupations that absorb displaced workers.

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<sup>22</sup> China's move towards a more balanced growth model might vacate space for other developing countries in labor-intensive manufacturing and provide further opportunities for traditional manufacturing activities. However, any such boost might be limited, not only because of the slowdown in global trade and ensuing reduced export opportunities, but also because moving such activities to lower-wage inland provinces and fast productivity growth from the rapid adoption of robot-based automation in China itself could keep Chinese exporters internationally competitive for longer. See also note 7 above.

## References:

Acemoglu D and Restrepo P (2017). Robots and jobs: evidence from US labor markets. Working Paper 23285. National Bureau of Economic Research (NBER), Cambridge (Mass).

Autor DH (2015). Why are there still so many jobs? The history and future of workplace automation. *Journal of Economic Perspectives*, 29(3): 3–30.

Autor DH and Dorn D (2013). The growth of low-skill service jobs and the polarization of the US labor Market. *American Economic Review*, 103(5): 1553–1597.

Autor DH, Levy F and Murnane RJ (2003). The Skill Content of Recent Technological Change: An Empirical Exploration. *Quarterly Journal of Economics*, 118(4): 1279–1333.

Baily MN and Bosworth BP (2014). US manufacturing: understanding its past and its potential future. *Journal of Economic Perspectives*, 28(1): 3–26.

De Backer K, Menon C, Desnoyers-James I and Moussiégt L (2016). Reshoring: myth or reality? OECD Science, technology and Industry Policy Papers No. 27, Paris. Available at [https://www.oecd-ilibrary.org/science-and-technology/reshoring-myth-or-reality\\_5jm56frbm38s-en](https://www.oecd-ilibrary.org/science-and-technology/reshoring-myth-or-reality_5jm56frbm38s-en).

Diao X, McMillan M and Rodrik D (2017). The recent growth boom in developing economies: a structural-change perspective. Working Paper 23132. National Bureau of Economic Research (NBER), Cambridge (Mass).

Felipe J and Mehta A (2016). Deindustrialization? A global perspective. *Economics Letters*, 149: 148–151.

Felipe J, Mehta A and Rhee C (2015). Manufacturing matters ... But it's the jobs that count. Available at: <http://jesusfelipe.com/wp-content/uploads/2015/07/SSRN-id2558904.pdf>.

Ford M (2015). *The Rise of the Robots*. London, Oneworld.

Frey CB, Osborne M and Holmes C (2016). Technology at work v2.0. The future is not what it used to be. Oxford Martin School and Citi Global Prospects and Solutions, Oxford. Available at [https://www.oxfordmartin.ox.ac.uk/downloads/reports/Citi\\_GPS\\_Technology\\_Work\\_2.pdf](https://www.oxfordmartin.ox.ac.uk/downloads/reports/Citi_GPS_Technology_Work_2.pdf).

Fu X, Kaplinsky R and Zhang J (2012). The impact of China on low and middle income countries' export prices in industrial-county markets. *World Development*, 40(8): 1483–1496.

Graetz G and Michaels G (2016). Robots at work. London School of Economics. Available at [http://personal.lse.ac.uk/michaels/Graetz\\_Michaels\\_Robots.pdf](http://personal.lse.ac.uk/michaels/Graetz_Michaels_Robots.pdf).

Hallward-Driemeier M and Nayyar G (2018). *Trouble in the Making? The Future of Manufacturing-Led Development*. Washington DC, World Bank.

Hanson G and Robertson R (2010). China and the Manufacturing Exports of Other Developing Countries. In R Feenstra and SJ Wei, eds, *China's Growing Role in World Trade*. Chicago, University of Chicago Press.

Haraguchi N (2014). Patterns of structural change and manufacturing development. Working Paper 07/2014. Research, Statistics and Industrial Policy Branch, UNIDO.

Haraguchi N, Cheng C and Smeets E (2017). The importance of manufacturing in economic development: has this changed? *World Development*, 93: 189–204.

International Federation of Robotics (2017). *World Robotics 2017 Industrial Robots*. Frankfurt am Main, International Federation of Robotics.

International Labour Office (2017). New automation technologies and job creation and destruction dynamics. Employment Policy Department Policy Brief, Geneva, May, available at [http://www.ilo.org/wcmsp5/groups/public/---ed\\_emp/documents/publication/wcms\\_553682.pdf](http://www.ilo.org/wcmsp5/groups/public/---ed_emp/documents/publication/wcms_553682.pdf).

Karabarbounis L and Neiman B (2014). The global decline of the labor share. *Quarterly Journal of Economics*, 129(1): 61–108.

Marcolin L, Miroudot S and Squicciarini M (2016). The routine content of occupations: new cross-country measures based on PIAAC. OECD Trade Policy Papers No. 188. Paris, OECD.

Mayer J (2017). How could the South respond to secular stagnation in the North? *World Economy*, 40(2): 314–335.

Midler C, Julien B and Lung Y (2017). *Rethinking Innovation and Design for Emerging Markets. Inside the Renault Kwid Project*. Boca Raton, Tayler and Francis.

Mokyr J, Vickers C and Ziebarth NL (2015). The history of technological anxiety and the future of economic growth: is this time different? *Journal of Economic Perspectives*, 29(3): 31–50.

Perez C (2016). Capitalism, technology and a green global golden age: the role of history in helping to shape the future. In Jacobs M and Mazzucato M, eds, *Rethinking Capitalism*. Economics and Policy for Sustainable and Inclusive Growth. Chichester, Wiley.

Pisano G and Shih WC (2012). *Producing Prosperity: Why America Needs a Manufacturing Renaissance*. Boston, MA: Harvard Business Review Press.

Rehnberg M and Ponte S (2017). From smiling to smirking? 3D printing, upgrading and the restructuring of global value chains. *Global Networks*, available at <http://onlinelibrary.wiley.com/doi/10.1111/glob.12166/full>.

Rodrik D (2015). From Welfare State to Innovation State. Project Syndicate, 14 January.

Sturgeon T (2017). The "New" Digital Economy and Development. Technical Notes on ICT for Development No. 8. UNCTAD, Geneva, available at [http://unctad.org/en/PublicationsLibrary/tn\\_unctad\\_ict4d08\\_en.pdf](http://unctad.org/en/PublicationsLibrary/tn_unctad_ict4d08_en.pdf).

UNCTAD (2016). The Catch-up Challenge: Industrialization and Structural Change. Chapter 3 in Trade and Development Report 2016. New York and Geneva, United Nations.

UNCTAD (2017). Robots, Industrialization and Inclusive Growth. Chapter 3 in Trade and Development Report 2017. New York and Geneva, United Nations.

Verhoogen EA (2008). Trade, quality upgrading, and wage inequality in the Mexican manufacturing sector. *Quarterly Journal of Economics*, 123(2): 489–530.

Wood A (2017). Variation in structural change around the World, 1985-2015: Patterns, causes, and implications. WIDER Working Paper 2017/34.

Wood A and Mayer J (2011). Has China de-industrialised other developing countries? *Review of World Economics*, 147(2): 325–50.

World Bank (2016). *Digital Dividends. World Development Report 2016*. Washington, DC, The World Bank.

Wübbecke J, Meissner M, Zenglein MJ, Ives J and Conrad B (2016). *Made in China 2025. The making of a high-tech superpower and consequences for industrial countries*. Berlin, Mercator Institute for China Studies.