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The future of work: challenges for job creation due to global demographic change and automation

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Abstract

We explore future job creation needs under conditions of demographic, economic, and technological change. First, we estimate the implications for job creation in 2020–2030 of population growth, changes in labor force participation, and the achievement of plausible target unemployment rates, disaggregated by age and gender. Second, we analyze the job creation needs differentiated by country income group. Finally, we examine how accelerated automation could affect job creation needs over the coming decades. Overall, shifting demographics, changing labor force participation rates, reductions in unemployment to the target levels of 8 percent for youth and 4 percent for adults, and automation combine to require the creation of approximately 340 million jobs in 2020–2030.

1. **Introduction**

As the International Labour Organization's (ILO's) landmark report *Work for a Brighter Future* (ILO, 2019) shows, the world of work is under transformation and many challenges lie ahead. More and more people worldwide find themselves in informal, precarious, and nonstandard forms of employment (ILO, 2018a); inequality is rising within most countries, widening the gap between those who benefit from economic development and those who are left behind (Atkinson et al., 2011; Piketty, 2014); the gender wage gap remains substantial in most countries despite decades of efforts to close it; automation is not only affecting the number of available jobs but also the quality of existing jobs and the potential of people to derive meaning from their work (Brynjolfsson and McAfee, 2014; Graeber, 2018); and finally, global demographic changes such as population growth and increasing labor force participation continue to add millions of people to the global workforce each year (see for example, United Nations, 2017).

In our contribution, we aim to quantify the challenges due to demographic shifts, changes in labor force participation, and displacement by industrial robots over the next decade. Providing enough jobs in the wake of these challenges and thereby keeping unemployment in check is important not only because unemployment is one of the public's top concerns (Gallup, 2014), but also because the unemployed tend to be unhappier and unhealthier than the employed and because long-term unemployment is one of the main factors driving manifest poverty. Therefore, projections of future global employment needs due to demographic changes and technological developments are of central importance for economists, policymakers, and the wider public.

In deriving the job creation needs over the coming decade we rely on the following techniques: i) standard demographic projections (Bloom et al., 2019) for changes in population size, changes in labor force participation, and the effects of specific unemployment targets; ii) extrapolations of current trends in automation under various scenarios combined with an application of the estimated job replacement by robots taken from recent seminal contributions by Acemoglu and Restrepo (2017a) and by Dauth et al. (2017). In our analysis, we find that between 2020 and 2030, more than 300 million new jobs will need to be created globally to accommodate i) an 8.9 percent increase in the working-age population, defined as those aged 15–64; ii) changing labor force participation; and iii) general improvements in the youth and adult unemployment rates to target levels of 8 percent and 4 percent, respectively. When we factor in the effects of automation, the job creation needs rise to more than 340 million. Examining these factors separately indicates that demographic changes will account for a far greater share of job creation needs over the coming decade than automation.

With respect to the global distribution of job creation needs, our results show that 98 percent of the increase in the working-age population (aged 15–64) in 2020–2030 is expected to occur in low- and lower-middle-income countries. This poses a challenge because these countries are also becoming more vulnerable to reshoring of production from low-income countries back to richer countries (Chu et al., 2013; Krenz et al., 2018). As far as the elderly population is concerned, the largest increases are expected in high- and upper-middle-income countries, with these countries accounting for 66 percent of the increase in the 65 and older population in 2020–2030. This poses the challenge of creating jobs for older workers, while at the same time, aging countries are investing most in automation (Abeliansky and Prettner, 2017; Acemoglu and Restrepo, 2017b, 2018c).

In terms of labor force participation, age-specific labor force participation rates drive overall changes, with declines in the 15–24 age group being of primary importance. Overall, labor force participation rates will decrease from 2020 to 2030 in all age and country income groups, except in the elderly population in high-income countries. Using target unemployment rates and predicted 2030 labor force participation, we estimate that only 11 percent of the global job creation needs will be for youths aged 15–24. We present important findings by gender as well: examining the effects of population change alone indicates that women account for only 27 percent of global job creation needs, with notable variation by country income level.

Three additional global demographic and economic aspects are worth mentioning. First, population aging affects the age composition of the labor force, as older workers stay active in the labor market for longer periods of time (Kühn et al., 2018). This shift presents the unique challenge of creating jobs that can accommodate an aging workforce. Second, the population and labor force of younger workers aged 15–24 has declined globally, mainly due to a decline in the youth working-age population in high- and upper-middle-income countries (Bloom et al., 2003, 2017). Additions to the youth labor force occur mainly in low- and lower-middle-income countries with major implications for the global distribution of entry-level jobs. Third, while overall worldwide migration is zero by definition and therefore the overall job-creation effects of migration cancel out at the global level, important second-order effects exist: if people migrate from countries with a low level of labor force participation to countries with a high level of labor force participation, the number of job seekers globally would rise. This implies that our demographic estimates of the number of required jobs up to 2030 are conservative.

Our paper is structured as follows: in Section 2 we present our main results of the job creation needs based on projected demographic shifts, labor force participation rates, and unemployment targets. We differentiate by age and gender and present the challenges for different country income groups. Section 3 is devoted to a new estimate of the potential displacement of workers by industrial robots. Finally, Section 4 offers our conclusions and summarizes the job creation challenges that we face in the coming decades.

2. Job creation needs due to demographic change

2.1 Job creation needs: global results

Based on the methodological framework and the data described in Appendix A, we estimate that between 2020 and 2030, 305 million jobs will need to be created given i) trends in population growth, ii) changes in the population's age structure, iii) changes in the gender composition of the labor force, iv) changes in age- and gender-specific labor force participation rates, and v) efforts to reach target unemployment rates of 8 percent for youth and 4 percent for adults.[1]

We construct our estimates using projected labor force participation rates for 2020 and 2030 and projected unemployment rates for 2020 from the United Nations and ILO (Tables 1 and 2).[2] For

[1] We use targets of at or less than 8 percent for youth unemployment (ages 15–24) and at or less than 4 percent for adult unemployment. For countries that are already below the 8 percent and 4 percent thresholds in 2010 or projected to be below these thresholds in 2020 or 2030, we simply carry forward their unemployment values.

[2] Tables 1 and 2 present summary statistics using projections from the United Nations and ILO. These are not our estimates, but rather the projections upon which we base our calculations.

2020–2030, population growth will remain the main driver of job creation needs, but the shift in the age structure toward age groups with a higher labor force participation rate, changes in age-specific labor force participation rates, and the specified unemployment targets will also contribute. In the following sections, we describe these channels separately.

Table 1: Summary statistics of labor force participation rates by age and gender (percent)

	2000		2010		2020		2030	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*
Global								
Age group								
15+	78.5	50.9	76	48.8	74.5	47.5	72.3	45.3
25+	84.4	53.5	83	52.3	81.4	51.1	78.9	48.6
65+	31.4	12.5	28.8	12.7	29.1	13.5	28.5	13.6
15–24	61.5	43.1	54.8	37.2	49.3	33.2	46.8	31.7
15–64	82.9	55.7	80.9	53.5	80.3	52.9	79.3	51.7

Notes:
1) Values represent net effects from beginning to end of period and do not reflect movement in the intervening years.
2) Global estimates represent approximately 99 percent of the global population due to lack of labor force participation rates for 14 countries: Antigua and Barbuda, Aruba, Curaçao, Federated States of Micronesia, Grenada, Kiribati, Marshall Islands, Mayotte, Nauru, Palau, Seychelles, South Sudan, State of Palestine, and Tuvalu.
3) Source: Authors' work derived from United Nations (2017) and ILO (2018c).

Table 2: Summary statistics of unemployment rates by age and gender (percent)

	2000		2010		2020	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
Global						
Age group						
15+	5.2	5.9	5.2	5.9	4.6	5.4
25+	3.7	4.4	3.9	4.5	3.5	4.3
15–24	11.1	11.4	11.3	12.1	11.4	12.5

Notes: See Table 1.

Job creation needs due to changes in the working-age population

In Table 3, we use United Nations projections for population growth and labor force participation rates in 2020 and 2030 to calculate global changes in population and labor force, disaggregated by gender. We find that the global working-age population will have increased by 516 million between 2010 and 2020, with the growth split quite evenly between males and females. An additional, smaller increase will occur between 2020 and 2030 of 451 million, representing 87 percent of the increase from the former period.[3] Figures B.1 and B.2 in Appendix B illustrate these changes by five-year age groups for males and females, respectively.

[3] Examining the 15+ population rather than the working-age population of 15–64 reveals a projected increase of roughly 714 million in 2010–2020 and 718 million in 2020–2030. As more people are projected to remain in the job

In 2010–2020, the youth working-age population (ages 15–24) will decrease by 8 million among males and 15 million among females (representing 1 and 3 percent decreases, respectively).[4] In 2020–2030, however, the youth working-age population is projected to grow by 50 million for males and 47 million for females, representing 8 percent growth for both genders. Changes in the youth working-age population are important because growth in the 15-24-year-old population in low-income and lower-middle-income countries will significantly contribute to employment needs in 2020–2030, as Section 2.2 explains.

The projected increase in the total 15+ population in 2020–2030 is roughly the same as the increase in 2010–2020. However, the projected increase in the 25+ population in the latter decade is only 84 percent of the increase in 2010–2020. This reflects the growth in the 15–24 age group in the latter time period that was absent in the former.

Job creation needs due to changes in population and labor force participation rates

Combining United Nations population projections in 2020 and 2030 with ILO projections for labor force participation rates in those years, we obtain estimates of changes in the global labor force in 2010–2020 and 2020–2030 (Table 3). In 2010–2020, global labor force participation rates among men 15 and older are projected to decrease by approximately 1.5 percentage points, with most of this shift attributable to a 5.5-percentage point decline among youth. The situation is similar for women aged 15 and older: labor force participation rates are expected to decline by 1.3 percentage points by 2020, with the largest decline of 4 percentage points among youth. Table 3 shows our calculations of how these shifts in labor force participation rates, combined with the aforementioned changes in population, will affect the labor force.

In 2020–2030, the decline in labor force participation rates (LFPR) is projected to be larger in magnitude than in the previous decade (2.2 percentage points for both men and women aged 15+). This decline is partially attributable to declines in youth (ages 15-24) LFPR, as labor force participation rates are projected to decrease by 2.5 percentage points among young men and 1.5 percentage points among young women in this decade.

Figures B.3 and B.4 in Appendix B depict these declines in labor force participation rates for males and females. The changes in population and labor force participation rates culminate in a decrease in the global labor force for younger age groups and an increase for older age groups. Figures B.5 and B.6 in Appendix B illustrate this labor force shift for males and females.

Figures 1 and 2 depict the change in the labor force in 2020–2030, which is a result of changes in both the working-age population and labor force participation rates. Changes in population and labor force participation rates result in a projected increase of 240 million in 2020-2030 among those aged 15–64 in the global labor force (Table 3).

market beyond age 65, a discussion regarding the parameters of the working-age population is warranted (see Sanderson and Scherbov, 2010; Crespo Cuaresma et al., 2014).

[4] Demographic trends in the 10 most populous countries in 2020—mainly in China and Brazil—can explain much of the gender difference in changes in the youth working-age population (United Nations, 2017). The female youth working-age population decreases sharply in 2010–2020 in these countries due to son preference and cohort aging. An overall increase in fertility mitigates this change in 2020–2030.

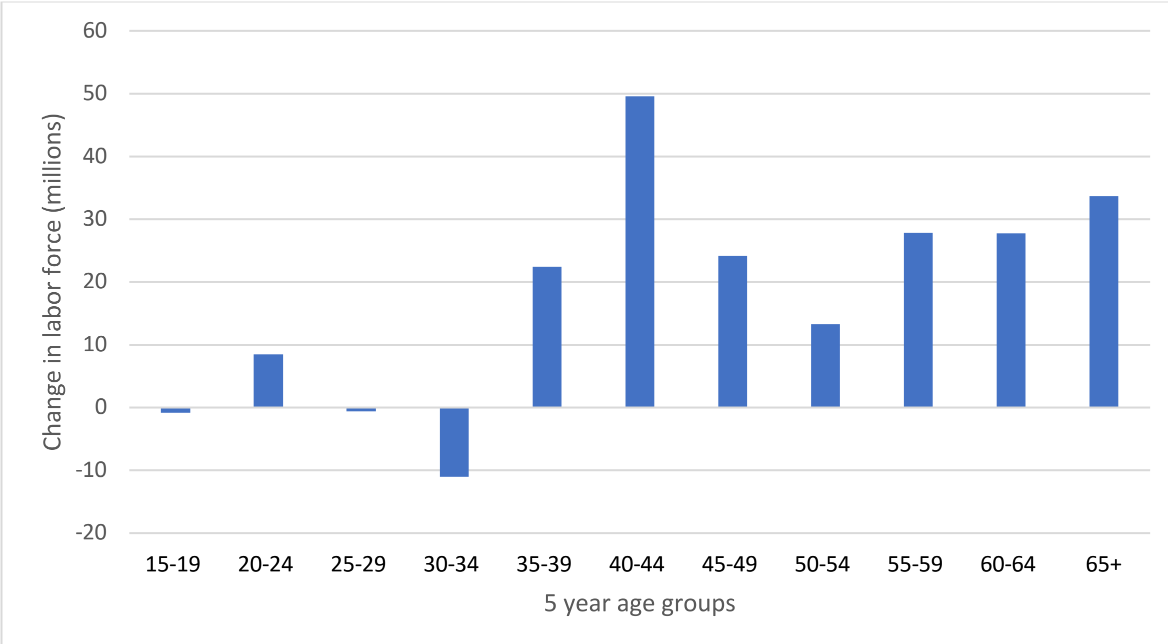

Figure 1: Change in male labor force, 2020–2030 (millions)
Source: Authors' work derived from ILO (2018c).

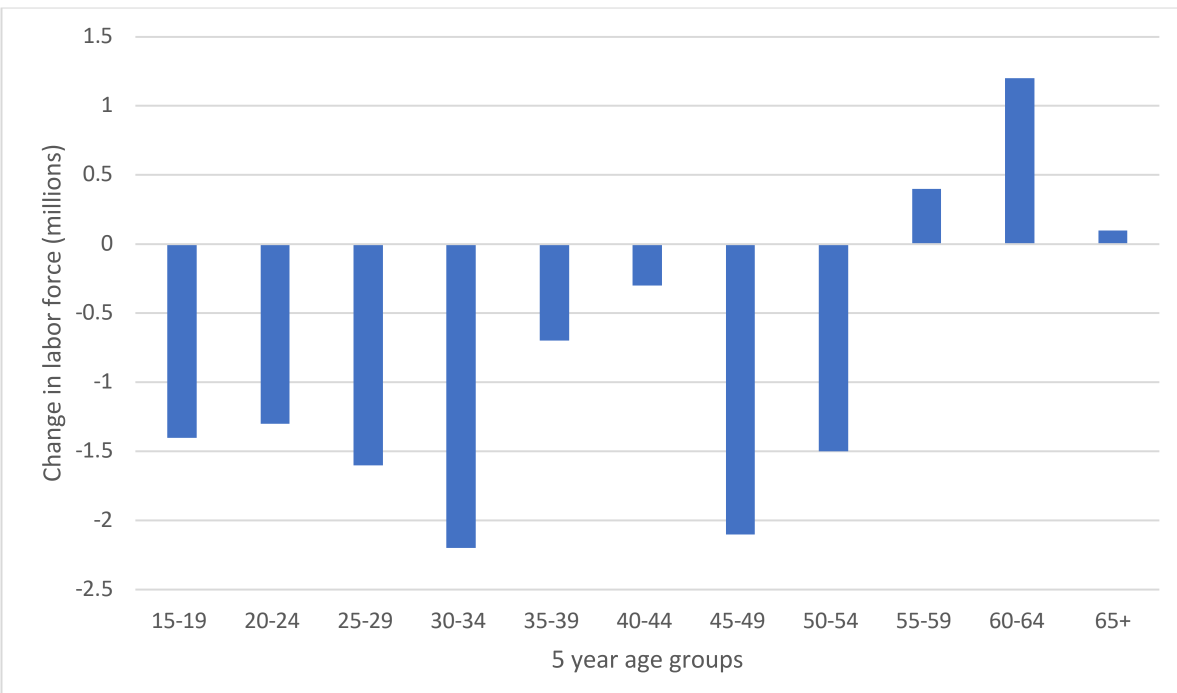

Figure 2: Change in female labor force, 2020–2030 (millions)
Source: Authors' work derived from ILO (2018c).

Table 3: Estimated changes in population and labor force in 2010–2020 and 2020–2030, by age and gender (millions)

	Change in population	**Change in labor force**

	2010–2020		2020–2030		2010–2020		2020–2030	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*
Global								
Age group								
15+	361	353	360	358	231	135	195	99
25+	369	368	310	311	269	164	187	93
65+	93	104	124	143	28	16	34	20
15–24	-8	-15	50	47	-38	-29	8	7
15–64	268	248	236	215	203	119	161	79

Notes:
1) Values represent net effects from beginning to end of period and do not reflect movement in the intervening years.
2) Population numbers are obtained from the United Nations' World Population Prospects: The 2017 Revision (United Nations, 2017) and thus refer to July 1 for each year indicated. Numbers are based on the medium-fertility variant. Note that population growth is fairly sensitive to the variant used.
3) Global estimates represent approximately 99 percent of global population due to lack of labor force participation rates for 14 countries: Antigua and Barbuda, Aruba, Curaçao, Federated States of Micronesia, Grenada, Kiribati, Marshall Islands, Mayotte, Nauru, Palau, Seychelles, South Sudan, State of Palestine, and Tuvalu.
4) Source: Authors' work derived from United Nations (2017) and ILO (2018c).

Job creation needs due to changes in population and labor force and adoption of target unemployment rates

Next, we analyze how changes in target unemployment rates affect our results (Table 4).[5] To this end, our first baseline results project the employment needs in 2020–2030 assuming constant unemployment rates and labor force participation rates at 2020 levels. Then we adopt target unemployment rates of 8 percent for youth (ages 15–24) and 4 percent for adults (aged 25+) and the ILO projections for 2030 labor force participation rates to analyze how these targets affect job creation needs as compared with the baseline results. If the 2020 unemployment rates projected by the ILO are lower than our proposed targets, we use those rates for our 2030 projections[6].

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[5] We use targets for 2030 unemployment but not for 2030 labor force participation in our demographic projections because the ILO does not provide projected unemployment rates for 2030, while the ILO does provide projected labor force participation rates for 2030. Because the difference between our projections of labor supply and the future job creation needs are absorbed in the residual of unemployment, we need to tie our hands with respect to this variable to make reasonable predictions of how many jobs will need to be created in 2030. There are two straightforward options to achieve this: i) using the projected 2020 unemployment rates and ii) using unemployment rates that have been suggested as targets in the past. We follow both approaches and rely on Bloom and McKenna (2015) for the particular values of target unemployment rates. Unemployment targets of 8 percent for youth and 4 percent for adults are ambitious, yet reasonably close to current estimates of full employment in the United States (U.S. Congressional Budget Office, Natural Rate of Unemployment (Long-Term)).
[6] In 2020, the ILO projects the global unemployment rate for people aged 15+ to be approximately 4.6 percent for men and 5.4 percent for women. Separating the two age groups (15–24 and 25+), the estimate amounts to roughly 11.4 percent for young men and 12.5 percent for young women and 3.5 percent and 4.3 percent for adult men and adult women, respectively. In the target-based approach, we do not assume different unemployment targets based on gender.

Based on Equation (5) in Appendix A, we combine the components described in the previous sections and find that employment growth amounts to 366 million workers globally between 2010 and 2020, which implies a growth rate of 12 percent (Table 4). Projecting forward to 2030, we arrive at the need to create 581 million jobs, a required employment growth of 17 percent. This calculation assumes constant 2020 unemployment and labor force participation rates.

When we use projected 2030 labor force participation rates and target unemployment rates in 2030, employment needs are projected to increase only by 305 million. This presents a 17 percent decline in job growth requirements compared with the previous decade's projections.

The drop can be attributed to declines in population growth and labor force participation among 15-24-year-old males: our estimates of job creation needs for young men are 82 percent lower when using 2030 labor force participation and target unemployment rates rather than 2020 data.

Our estimates of job creation needs using 2030 labor force participation and target unemployment rates are 44 percent lower for males aged 25+ and 40 percent lower for females aged 25+ than our estimates using constant 2020 data. This discrepancy may be due to the delayed effects of declines in population growth and labor force participation that occurred for youth (ages 15-24) in 2010–2020. Effects on the youth population in the previous decade may appear in the adult labor force of the following decade.

We find gender imbalances in both employment needs in 2010–2020 and projected employment needs in 2020–2030. Due to substantial differences in labor force participation rates, nearly equal changes in male and female populations do not translate into equal changes in the labor force or in employment. While female population growth in 2010–2020 accounts for approximately 50 percent of all population growth, women account for only 37 percent of the changes in the labor force and 37 percent of changes in employment. This imbalance is due to women having substantially lower labor force participation rates than men; in 2020, the projected participation rates are 74.5 percent for men and 47.5 percent for women aged 15 and older. The projected trends for 2020–2030 are nearly identical, deviating only by a few percentage points, and thus this gap between male and female labor force participation and employment is not projected to narrow by 2030.

Table 4: Estimated changes in employment in 2010–2020 and 2020–2030, by age and gender (millions)

	Projected change in employment 2010–2020		**Change in employment 2020–2030**			
			Constant 2020 unemployment rate and LFPR		**Unemployment rate targets of at or less than 8 percent for youth and at or less than 4 percent for adults (and 2030 LFPR)**	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
Global						
Age group						
15–24	-34	-26	94	14	17	15
15+	232	134	414	167	198	107
25+	267	160	320	153	180	92

Notes:
1) Values represent net effects from beginning to end of period and do not reflect movement in the intervening years.

2) Population numbers are obtained from the United Nations' World Population Prospects: The 2017 Revision (United Nations, 2017) and thus refer to 1 July for each year indicated. Numbers are based on the medium-fertility variant. Note that population growth is fairly sensitive to the variant used.
3) Global estimates represent approximately 99 percent of global population due to lack of labor force participation rates for 14 countries: Antigua and Barbuda, Aruba, Curaçao, Federated States of Micronesia, Grenada, Kiribati, Marshall Islands, Mayotte, Nauru, Palau, Seychelles, South Sudan, State of Palestine, and Tuvalu.
4) Source: Authors' work derived from United Nations (2017) and ILO (2018c).

2.2 Job creation needs: country income group results

Our results indicate that the job creation challenge in 2020–2030 will be concentrated in low- and lower-middle-income countries, where population growth is above the world average and the youth population is increasing. Low- and lower-middle-income countries are projected to account for almost 70 percent of job creation needs between 2020 and 2030. This concentration of job creation needs is in large part attributable to these countries' disproportionate share of population growth: these countries account for 75 percent of all population growth in the coming decade. In the following sections, we outline the effects of population growth, changes in LFPR, and theoretical achievement of target unemployment rates on job creation needs, disaggregated by country income group.

Job creation needs due to changes in the working-age population by country income group

As in the global projections in Section 2.1, we use ILO LFPR figures for 2020 and 2030 and ILO unemployment rate projections for 2020. Tables 5 and 6 summarize these labor force participation rates and unemployment rates by country income group.

We calculate changes in population and labor force in 2010–2020 and in 2020–2030; Table 7 presents our estimates by country income group. Overall population growth is projected to concentrate in low- and lower-middle-income countries in both the 2010–2020 and 2020–2030 time periods. Low- and lower-middle-income countries will account for 70 percent and 75 percent of the growth of the population aged 15 and older in 2010–2020 and 2020–2030, respectively.

An even more striking dichotomy arises when we examine population growth by country income group and age group. In 2010–2020, the youth working-age population (ages 15–24) is projected to decline globally among males and females. This decrease can be attributed to declining youth populations in high- and upper-middle-income countries. In absolute values, a decline of 10 million and 90 million youths aged 15–24 is expected to occur in high- and upper-middle-income countries, respectively, between 2010 and 2020. By contrast, an increase of 76 million young working-age people is expected to occur in low- and lower-middle-income countries combined in that decade.

In 2020–2030, an addition of 14 million young people aged 15-24 is expected to occur among high- and upper-middle-income countries, compared with an expected addition of 82 million among low- and lower-middle-income countries.

The projections for the 15–64 age group are quite similar: 98 percent of the increase in the working-age population from 2020 to 2030 is expected to come from low- and lower-middle-income countries.

These contrasts in global population dynamics have profound implications for future job creation needs and related research. For example, one might plausibly conjecture that low- and lower-middle-income countries may benefit from more "entry-level" jobs to employ their rising youth population, whereas high- and upper-middle-income countries would benefit from less physically demanding jobs that are more suited to an increasing elderly workforce.

Service sector jobs may already represent employment opportunities for older workers in industrialized countries. In this case, the obstacles to employment of the older workforce would plausibly be a lack of jobs with comparably high wages for older workers who have been displaced from their original jobs and mandatory retirement policies that prevent them from continuing to work. However, countries with an aging workforce might invest more in automation than in changing legislation to promote employment of the elderly. Indeed, evidence exists that aging countries invest more in automation and thereby use industrial robots to compensate partially for the challenges of a shrinking workforce (Abeliansky and Prettner, 2017; Acemoglu and Restrepo, 2017b, 2018c).[7] Acemoglu and Restrepo (2018c), for example, show that population aging explains between 40 percent and 65 percent of the adoption of industrial robots across countries even when controlling for income levels.

On top of these aspects, automation exacerbates a trend toward reshoring, in which many firms that previously offshored production to lower-income countries are bringing production back to higher-income countries (Chu et al., 2013; Krenz et al., 2018). This could hurt lower-income countries' prospects for using a strategy of export-led growth to meet their rising demand for employment.

Job creation needs due to changes in population and labor force participation rates by country income group

We use the changes in working-age population outlined above, combined with ILO LFPR projections for 2020 and 2030, to calculate changes in the labor force in 2010–2020 and in 2020–2030 by country income group (Table 7). Between 2010 and 2020, labor force participation rates are projected to decrease, except for women and the older population in high-income countries[8]. For all other country income groups, labor force participation rates will decline across gender and age groups.

Young working-age men will experience the greatest percentage point decreases across all income levels. The general trend is that the percentage point decrease in youth male participation will be greater in countries with higher income, excluding high-income countries, which seem to break this pattern. In all country income groups, age-specific labor force participation rates are expected to drive participation rate changes, with declines in the 15–24 age group being a primary driver of overall declines in participation.

7 In estimating and interpreting the correlation between aging and automation among countries, one needs to be cautious to consider the effects of aging on offshoring that could be used as an alternative to automation (see, for example, Abeliansky et al., 2015; Krenz et al., 2018).

8 Participation rates will rise by 2.7 percentage points for working-age women in high-income countries and by 2.9 and 2.3 percentage points for men and women aged 65 and older.

Similar to the trends from 2010-2020, labor force participation rates decrease from 2020 to 2030 in all age and country income groups, except in the elderly population in high-income countries. Notably, this increase in elderly workforce participation does not hold true for other country income groups. While age-specific declines continue to drive overall declines in labor force participation in this latter decade, declines in the adult population (those aged 25 and above) may also contribute to our projections.

Table 7 shows the impact of changes in population and labor force participation rates on the number of people in the labor force, disaggregated by age, gender, and country income group. Population growth in low-income and lower-middle-income countries mitigates the aforementioned declines in LFPR, leading to a sizeable increase in the labor force from 2020 to 2030. For these country income groups, we project a combined labor force increase (for ages 15+) of 109 million.

Table 5: Summary statistics of labor force participation rates by age, gender, and country income group (percent)

	2000		2010		2020		2030	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*
Country income group								
High income								
15+	71	50.7	69.1	51.9	68	52.5	65.3	50.9
25+	74.9	51.4	73.4	53.6	71.6	54	68.6	52.4
65+	14.9	6.5	16.2	8.1	19.1	10.4	20.3	11.5
15–24	53.1	46.8	47.6	42.4	46.6	42.5	44.3	40.8
15–64	80.2	61.3	79.2	63.4	80	66.1	79.5	66.6
Upper-middle income								
15+	80	59.8	76.3	56	74.3	53.7	69.7	49.3
25+	85	62.1	82.2	59.3	79.5	56.7	74.7	52
65+	32.3	14	26.5	12.3	25.8	12.3	23.9	11.7
15–24	63.9	52.1	56.2	44	48.6	37.2	44.7	34
15–64	84.3	65	81.3	61.5	81.2	60.9	78.8	58.5
Lower-middle income								
15+	80.7	38.1	78.7	36.1	77	35.4	76	34.8
25+	89.3	41.3	88.7	40.1	87.4	39.6	85.8	38.8
65+	47.3	15.5	43.7	15.7	42.3	15.5	40.7	15.4
15–24	61.5	30.9	54.2	25.9	47.4	22.4	44.7	21.3
15–64	82.9	40	81.2	37.9	79.9	37.4	79.7	37.3
Low income								
15+	82	65.9	80.1	64.2	78.6	64	78.3	63.4
25+	91.3	70.4	89.9	69.5	88.6	69.8	87.9	69
65+	64.8	40.7	61.5	39.7	58.6	39	56.6	38.1
15–24	65.4	57.3	62.6	54.2	60.2	52.5	58.6	51.3
15–64	82.9	67.6	81.2	65.9	79.7	65.7	79.5	65.3

Notes:

1) Values represent net effects from beginning to end of period and do not reflect movement in the intervening years.
2) Global estimates represent approximately 99 percent of global population due to lack of labor force participation rates for 14 countries: Antigua and Barbuda, Aruba, Curaçao, Federated States of Micronesia, Grenada, Kiribati, Marshall Islands, Mayotte, Nauru, Palau, Seychelles, South Sudan, State of Palestine, and Tuvalu.
3) Countries are classified into country income groups based on the World Bank's country income classifications, as set on July 1, 2016.
4) Source: Authors' work derived from United Nations (2017) and ILO (2018c).

Table 6: Summary statistics of unemployment rates by age, gender, and country income group (percent)

	2000		2010		2020	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
Country income group						
High income						
15+	6.3	7.5	8.3	8.1	4.8	5.5
25+	5.1	6.3	7	7	4	4.8
15–24	14.1	14	18.6	16.5	12.1	11.3
Upper-middle income						
15+	5.9	5.7	6	5.7	6	6
25+	4.4	4.3	4.6	4.4	4.9	4.9
15–24	12.1	11.3	12.6	12.5	14.4	15.5
Lower-middle income						
15+	4.1	5.3	3.3	4.9	3.5	5.2
25+	2.3	3.1	1.8	3.1	2	3.5
15–24	10.1	11.9	9.2	12.1	11.1	14.5
Low income						
15+	4.4	4.2	4.1	4.5	3.6	3.8
25+	3.1	3.1	3	3.5	2.7	2.9
15–24	7.6	6.8	7	7	6.3	6.1

Notes: See Table 5.

Table 7: Estimated changes in population and labor force in 2010–2020 and 2020–2030, by age, gender, and country income group (millions)

	Change in population				**Change in labor force**			
	2010–2020		2020–2030		2010–2020		2020–2030	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*
Country income group								
High income								
15+	33	28	22	21	18	18	2	3
25+	37	32	22	20	21	20	3	4
65+	25	25	27	27	7	5	7	5
15–24	-5	-5	0	0	-3	-2	-2	-1

15–64	8	3	-5	-7	11	13	-5	-2
Upper-middle income								
15+	82	82	70	69	42	22	0	-12
25+	126	128	61	63	80	52	4	-9
65+	42	49	55	66	10	6	10	7
15–24	-44	-46	8	6	-38	-31	-3	-3
15–64	40	33	15	4	32	16	-10	-19
Lower-middle income								
15+	190	186	194	194	126	57	130	59
25+	168	169	173	173	134	62	129	57
65+	24	27	38	45	9	4	14	7
15–24	22	16	22	21	-8	-5	1	1
15–64	166	159	157	150	117	53	117	52
Low income								
15+	57	57	74	74	44	38	62	50
25+	37	39	53	54	34	29	51	40
65+	3	4	4	5	1	1	3	2
15–24	20	18	20	19	11	9	11	10
15–64	54	54	69	68	43	36	60	48

Notes:
1) Values represent net effects from beginning to end of period and do not reflect movement in the intervening years.
2) Population numbers are obtained from the United Nations' World Population Prospects: The 2017 Revision (United Nations, 2017) and thus refer to July 1 for each year indicated. Numbers are based on the medium-fertility variant. Note that population growth is fairly sensitive to the variant used.
3) Global estimates represent approximately 99 percent of global population due to lack of labor force participation rates for 14 countries: Antigua and Barbuda, Aruba, Curaçao, Federated States of Micronesia, Grenada, Kiribati, Marshall Islands, Mayotte, Nauru, Palau, Seychelles, South Sudan, State of Palestine, and Tuvalu.
4) Countries are classified into country income groups based on the World Bank's country income classifications, as set on July 1, 2016.
5) Source: Authors' work derived from United Nations (2017) and ILO (2018c).

Job creation needs due to changes in population and labor force participation and adoption of target unemployment rates by country income group

Table 8 shows that the distribution of job creation needs changes quite drastically among country income groups in 2010–2020 and in 2020–2030. In the earlier decade, nearly 70 percent of projected job creation requirements concentrate in low- and lower-middle-income countries. High-income countries comprise only 14 percent of employment needs. The projected employment requirements are fairly evenly split between men and women, except in upper- and lower-middle-income countries, where approximately 30 percent of projected required jobs are for women.

In 2020–2030, using target unemployment rates and predicted 2030 labor force participation rates, we estimate that 94 percent of job creation needs will come from low- and lower-middle-income countries, with an absolute value of only 19 million jobs being required in high- and upper-middle-income countries.

Only 11 percent of the global job creation needs will be for youths in 2020–2030. In high- and upper-middle-income countries, youths will account for 21 percent of new employment requirements; in low- and lower-middle-income countries, they will account for 10 percent. This suggests that the previous decade's increase in youth population may be a primary driver of increasing adult employment requirements by 2030 in low- and lower-middle-income countries. Another implication is that in 2020–2030 an increasing youth population, while still an important factor, will no longer be the main driver of employment needs.

Drivers of employment needs: country income group results

Revisiting our decomposition analysis, in which we hold unemployment and labor force participation rates constant at 2020 levels to isolate the effect of population changes on the employment outlook, shows that low- and lower-middle-income countries account for approximately 70 percent of job creation needs by 2030. This result suggests that changes in labor force participation, rather than population growth, explain the projected dominance of low- and lower-middle-income countries in the growth of job creation needs in 2020–2030.

In particular, upper-middle-income countries account for 29 percent of job creation needs at constant 2020 unemployment and labor force participation rates, but account for only 3 percent at target unemployment and projected 2030 labor force participation. The projected decline of labor force participation in upper-middle-income countries, particularly among youth, is thus a major driver of the reduction in these countries' projected job requirements. A similar situation arises for high-income countries, which account for approximately 10 percent of job creation needs when we solely examine the effects of population change, but only 3 percent when we include target unemployment rates and the ILO projections of 2030 labor force participation.

A noteworthy divide occurs along gender lines when we look at the effects of population change alone. Women account for only 27 percent of global job creation needs in this scenario. In high-income countries, women account for none of the new employment needs at constant 2020 unemployment and labor force participation. In (upper- and lower-) middle-income countries, they account for 26 percent; in low-income countries, for 40 percent.

However, using our projections with target unemployment rates and 2030 labor force participation, women account for 67 percent of job creation needs in high-income countries. In upper-middle-income countries, a decrease in employment requirements is projected for women in this scenario. In low- and lower-middle-income countries, women account for 44 and 31 percent of new employment needs.

This suggests that the size of the labor force has a critical impact on job creation needs for women in all country income groups and particularly in high- and upper-middle-income countries, where it partially accounts for the increase and decrease, respectively, of the percentage of job creation needs that are attributed to women relative to men.

Table 8: Estimated changes in employment in 2010–2020 and 2020–2030, by age, gender, and country income group (millions)

	Projected change in employment	**Change in employment 2020–2030**	
		Constant 2020	**Unemployment rate targets of at or less than 8**

	2010–2020		unemployment rate and LFPR		percent for youth and at or less than 4 percent for adults (and 2030 LFPR)	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
Country income group						
High income						
15–24	0	0	2	-1	0	0
15+	29	24	16	0	3	6
25+	29	24	19	1	3	6
Upper-middle income						
15–24	-35	-29	28	2	2	2
15+	40	19	116	40	13	-3
25+	74	48	103	39	10	-5
Lower-middle income						
15–24	-10	-6	53	6	5	5
15+	120	53	213	75	132	60
25+	130	59	184	74	126	55
Low income						
15–24	10	9	12	7	11	9
15+	43	37	51	34	60	48
25+	33	29	40	28	49	39

Notes:
1) Values represent net effects from beginning to end of period and do not reflect movement in the intervening years.
2) Population numbers are obtained from the United Nations' World Population Prospects: The 2017 Revision (United Nations, 2017) and thus refer to 1 July for each year indicated. Numbers are based on the medium-fertility variant. Note that population growth is fairly sensitive to the variant used.
3) Global estimates represent approximately 99 percent of global population due to lack of labor force participation rates for 14 countries: Antigua and Barbuda, Aruba, Curaçao, Federated States of Micronesia, Grenada, Kiribati, Marshall Islands, Mayotte, Nauru, Palau, Seychelles, South Sudan, State of Palestine, and Tuvalu.
4) Countries are classified into country income groups based on the World Bank's country income classifications, as set on July 1, 2016.
5) Source: Authors' work derived from United Nations (2017) and ILO (2018c).

3. Job creation needs due to automation

Examples of recent successes in automation abound: industrial robots are widely used in the automotive and electronic industries, replacing assembly-line workers; three-dimensional (3D) printers, requiring minimal human engagement, are used to produce medical implants and spare parts that are needed only infrequently; and devices based on machine learning are used to write reports and newsflashes, to reply to customer requests, and to search for precedent cases in law firms, largely without human guidance (for these and further examples, see Abeliansky et al., 2015; Ford, 2015; IFR, 2018). If self-driving cars and trucks were adopted on a large scale—as seems plausible in the not-too-distant future—the jobs of a substantial number of people currently employed as drivers worldwide could be threatened.

While automation comprises the use of industrial robots, 3D printing, artificial intelligence–based applications in services, and some forms of information and communication technologies, the empirical literature uses the number of operative industrial robots as published by the International Federation of Robotics (IFR) as an indicator of automation (Acemoglu and Restrepo, 2017a; Dauth et al., 2017, Graetz and Michaels, 2018). But even when restricting to this measure, which does not capture all previously described aspects, we observe a strong increase in automation over the past decades. According to IFR (2018), industrial robots increased globally from about 400,000 in 1990 to 2.1 million in 2017. Over the past five years, the growth rate in industrial robots averaged 11 percent worldwide, outpacing economic growth and population growth by far in most countries. In some countries, such as China and Vietnam, the number of industrial robots has even quadrupled over the past decade. These developments have sparked intense debates on the threat of automation to employment (cf. Ford, 2015; Arntz et al., 2017; Frey and Osborne, 2017).

With respect to the overall evolution of employment, recent theoretical research[9] suggests that robots are indeed substituting for workers, particularly those with lower skills, but that compensation effects are attenuating the net loss of employment due to automation. For example, i) people who are displaced in the manufacturing sector often find jobs in the service sector (Autor and Dorn, 2013; Dauth et al., 2017); ii) the production and maintenance of robots requires human workers (as long as this process is not fully automated) and, more generally, new tasks that are initially nonautomatable are continually created in technologically advanced economies (Hémous and Olsen, 2016; Acemoglu and Restrepo, 2018a); iii) the use of robots increases productivity, such that goods produced by robots become cheaper, leading to an income effect that raises demand for other goods that are still produced predominantly by human workers and thus increases employment in the production of these other goods (Acemoglu and Restrepo, 2018b); and iv) a decrease in labor market tightness due to robots leads to endogenous firm creation in models of the labor market with search and matching frictions because the better availability of workers allows more firms to enter the market, which creates employment opportunities (Cords and Prettner, 2019; Guimarães and Mazeda Gil, 2019). Recent empirical research has shown that these compensation mechanisms indeed alleviate the net loss of employment due to automation (Acemoglu and Restrepo, 2017a; Dauth et al., 2017).

Up to now, determining the potential future effects of automation on employment has focused predominantly on the technological feasibility of the substitution of human work by robots.[10] Regarding this technological feasibility, calculations published in refereed journals range from 9 percent of the total number of jobs (Arntz et al., 2017) to 47 percent (Frey and Osborne, 2017). However, firms base the decision to replace workers with robots not merely on technological possibilities but on economic considerations. Replacing a worker with an expensive robot may simply not pay off. In addition, robots are costly to maintain and still rather inflexible—once they have been programmed (or trained, as in the case of machine learning algorithms) for a particular task, changing the task may be difficult. Finally, robots take time and resources to construct, such that the technological feasibility only indicates an upper bound of the number of jobs that robots could substitute in a particular domain. In the near future, the main aspect that will constrain widespread automation will likely be meeting the demand for the production/supply of robots. This bottleneck, together with the depreciation of the existing stock of robots, should be considered when projecting the number of jobs that might be lost to automation. Therefore, we delve into the details of the challenge that automation poses for future job creation and provide a novel projection of how many jobs industrial robots threaten up to 2030, relying on both the *technological* and *economic* feasibility of the substitution of workers by robots.

[9] Only recently has the literature debated the economic consequences of automation. See, for example, Sachs and Kotlikoff (2012), Benzell et al. (2015), Sachs et al. (2015), Hémous and Olsen (2016), Abeliansky and Prettner (2017), Acemoglu and Restrepo (2017a,b; 2018a,b,c), Dauth et al. (2017), Prettner and Strulik (2017). Bloom et al. (2019), Lankisch et al. (2019), Prettner (2019), and Venturini (2019).

[10] An exception is the recent contribution by Bloom et al. (2019) that we extend in our analysis.

In so doing, we base our analysis of the job creation needs generated by automation on the following method. First, we extrapolate the growth rate of the stock of industrial robots from 2010 to 2017, as obtained from IFR (2018), and calculate a baseline projection in which we assume that this growth rate stays constant until 2030 (for a description of the data and the projections see Appendix C).[11] In addition, we project a low robot-adoption scenario, in which we assume that the average growth rate of the stock of operative industrial robots decreases by 50 percent from 2010–2017 to 2017–2030. In an alternative high robot-adoption scenario, we assume that the average growth rate in 2010–2017 increases by 50 percent over the period 2017–2030. Allowing for a 50 percent decrease in the average growth rate in the stock of robots accounts for the fact that many countries started with so few industrial robots that subsequent growth rates have been rather high and might likely decrease in the future. Also allowing for an alternative scenario with a 50 percent increase in the average growth rate of the stock of robots accounts for the fact that some large countries, notably China, are planning to increase investments in automation substantially (see, for example, Cheng et al., 2019; Giuntella and Wang, 2019). Thus, under very different scenarios, we get a range of the plausible operative stock of industrial robots in 2030.

Second, we multiply the resulting number of industrial robots in the year 2030 under the different scenarios by the estimated number of manufacturing jobs that robots could substitute according to two recent studies. Acemoglu and Restrepo (2017a) show that in the United States, each additional industrial robot replaces 6.2 manufacturing workers, whereas Dauth et al. (2017) show that in Germany, each additional industrial robot replaces only two manufacturing workers. Because the results of these two studies vary widely, we believe that the corresponding adoption scenarios span a range of plausible estimates for other countries also. However, a need clearly exists for additional systematic analyses in low-income countries that lead to estimates that are comparable to those of Acemoglu and Restrepo (2017a) and Dauth et al. (2017). Currently, the data are not available at a disaggregated level for low-income countries in the IFR database.

Because we are interested in the number of jobs that need to be created in other parts of the economy to accommodate the workers who are substituted by robots mainly in manufacturing, our calculations refer to the gross loss in employment due to automation. The previously mentioned compensation mechanisms would ensure that some of the jobs required to keep unemployment in check in the wake of automation would be created endogenously, such that the net loss in employment due to automation will be substantially lower. Altogether, our projections yield a range of estimates for the number of jobs that will have to be created (either by endogenous mechanisms or by other forces) to prevent unemployment from rising due to automation.

Table 9 displays the results of our projections for the world as a whole and for the regions "Africa," "Asia and Australia," "Europe," "North America," and "South America," for which the IFR provides aggregate data. The numbers reflect our preferred specification, in which the stock of robots in 2030 is calculated according to projections based on the perpetual inventory method and an assumed depreciation rate of robots of 10 percent. The data used for the perpetual inventory method are the data on robot stocks and deliveries from IFR (2018). In Appendix D,

11 Given that many countries started with few industrial robots but increased their stock of robots substantially in percentage terms over the last few years, the calculated average growth rates might overstate future adoption. This provides an additional reason for including a low robot-adoption scenario.

we assess our results' robustness by assuming 5 percent and 15 percent rates of depreciation in the perpetual inventory method and by using raw IFR data for our projections. Note that we find the numbers based on the perpetual inventory method to be more accurate because the IFR assumes the full depreciation of a robot after 12 years of operation, but assumes zero depreciation in the intervening 11 years.

Under the medium variant for the adoption of robots (in which the growth rate of the stock of industrial robots in 2017–2030 is the same as the calculated growth rate in 2010–2017), our results imply a substitution of 37.9 million jobs worldwide by industrial robots by 2030 when following Acemoglu and Restrepo's (2017a) high-displacement scenario. Using the same method to assess different regions and considering that robot adoption has been fastest in Asia, we find a gross loss of employment of 27.4 million jobs in Asia and Australia, 5 million jobs in North America, 5.3 million jobs in Europe, 0.3 million jobs in South America, and 0.09 million jobs in Africa. The reasons for the dominance of Asia in terms of the aggregate number of jobs are that the population is largest there and that recent growth rates of the stock of industrial robots have been comparatively high in China due to massive automation investments (Cheng et al., 2019; Giuntella and Wang, 2019). In the case of Dauth et al.'s (2017) low-displacement scenario, all numbers fall by a factor of 3.2 (the difference between the two estimates of the substitutability of workers by robots by Acemoglu and Restrepo, 2017a, and by Dauth et al., 2017) such that only 12.2 million jobs would be replaced worldwide by industrial robots in 2030.

Note that the regional numbers do not necessarily add up to the worldwide numbers because of differential trends in the various regions over the period 2010–2017. For example, growth in the stock of robots between 2010 and 2017 was particularly high in Asia and Australia. Extrapolating this growth rate implies very high numbers for the job creation needs due to automation in this region. In the high-adoption scenario, the number of jobs that will be substituted by robots thus even exceeds the figures for the world as a whole, which are calculated based on the average growth rate over all regions.

Table 9: Number of jobs that industrial robots could substitute in 2030 (in millions), worldwide and by region, according to projections based on the perpetual inventory method and an assumed 10 percent depreciation rate of robots (baseline data used for the perpetual inventory method: IFR, 2018)

Adoption	Displ.	World	Africa	Asia and Australia	Europe	North America	South America
low	high	20.49	0.05	13.67	3.58	2.74	0.15
	low	6.61	0.01	4.41	1.16	0.89	0.05
medium	high	37.92	0.09	27.38	5.28	4.96	0.33
	low	12.23	0.03	8.83	1.70	1.60	0.11
high	high	68.26	0.18	52.96	7.68	8.75	0.69
	low	22.02	0.06	17.08	2.48	2.82	0.22

Notes: The figures refer to the number of workers (in millions) who can be substituted by industrial robots in the year 2030, according to a combination of three scenarios in terms of the adoption of robots and two scenarios in terms of the potential displacement of workers by robots. "Adoption" refers to the calculation of projected industrial robots in the year 2030. The "medium" variant projects the average growth rate in the number of industrial robots from 2010 to 2017 forward to 2030. The "low" variant assumes that the projected growth rate drops by 50 percent, whereas the "high" variant assumes that the projected growth rate increases by 50 percent. "Displ." refers to the two displacement scenarios. The "high" variant relies on the estimates of Acemoglu and Restrepo (2017a), wherein one industrial robot replaces 6.2 workers in manufacturing in the United States. The "low" variant refers to the estimates of Dauth et al. (2017), wherein one industrial robot replaces two manufacturing workers in Germany.

The IFR data provides information either by region, world aggregate, or at the country level for a limited group of more than 70 countries. For this reason, we cannot project the job creation needs due to automation for the same country income groups used in Section 2. To indicate the differential effects of automation in the different country income groups, we do the projections for three large countries from the groups of high-income countries, upper-middle-income countries and lower-middle-income countries in Table 10.[12] China has been investing heavily in industrial robots in recent years—therefore, the job creation needs are extremely high in absolute values and sometimes exceed the world aggregate from Table 9. This is, of course, due to the fact that the recent growth rate of the stock of robots in China was very high. Thus, we refrain from calculating a high-adoption scenario for the individual countries and denote the medium-adoption variant from Table 9 as the high-adoption scenario at the country level. At this stage, it is important to note that the high-adoption scenario at the world level was introduced precisely because of the high growth rate of the stock of robots in some countries, notably in China, so it would make no sense to apply another high-adoption scenario for the already very high growth rates in these countries. In general, we observe that some countries that are investing heavily in automation (China and Vietnam) are expected to face a high amount of labor replacement by automation in 2030, whereas the increase will be more modest in countries that already have a comparatively high stock of industrial robots such that the recent growth rates in the stocks were already lower (Germany, Japan, United States). Finally, some countries such as Brazil, India, Indonesia, and Russia do not invest heavily in automation and will thus face a comparatively lower replacement of labor by automation in 2030.

Table 10: Number of jobs that industrial robots could substitute in 2030 (in millions), by selected countries (of different income groups), according to projections based on the perpetual inventory method and an assumed 10 percent depreciation rate of robots (baseline data used for the perpetual inventory method: IFR, 2018)

		High income			Upper-middle income			Lower-middle income		
Adoption	Displ.	USA	Germany	Japan	China	Russia	Brazil	Vietnam	India	Indonesia
low	high	1.98	1.35	2.12	22.30	0.03	0.12	1.43	0.31	0.20
	low	0.64	0.44	0.68	7.19	0.01	0.04	0.46	0.10	0.06
high	high	3.10	1.90	2.17	150.69	0.03	0.26	16.62	1.01	0.88
	low	1.00	0.61	0.70	48.61	0.01	0.08	5.36	0.33	0.28

Notes: See Table 9

Unfortunately, the data on automation do not allow analyses with respect to the job creation needs differentiated by age or differentiated by gender. While, to our knowledge, estimates on the replacement of workers by robots differentiated by age are not yet available, we could, in principle, use estimates from the literature on the gender-specific effects of automation.

[12] For the low-income group, only data for the Democratic Republic of Korea is available at the country level in the IFR database, such that we refrain from doing the projections for this group. We had considered including the projections for the group "Other Africa" (all African countries except Egypt, Morocco, South Africa, and Tunisia), but this group also includes many countries from other income groups so the projections would not be informative.

However, the views in the literature on this aspect vary widely. On the one hand, Acemoglu and Restrepo's (2017a) study using U.S. data finds that the adverse effects of automation on employment are about 1.5–2 times greater for men than for women. On the other hand, Brussevich et al. (2018) use different data and a different definition of automation to portray an alternative scenario in which automation harms women more based on the authors' observation that women perform more routine tasks and participate less in sectors related to science, technology, engineering, and mathematics, which are expected to have a high demand for labor even in more robot-intensive work environments in the future.

Overall, our results illustrate the potential of automation, but the exact numbers should be taken with caution because they are based on projections that necessarily rely strongly on the underlying assumptions, on recent growth trends, and on the estimated replacement rates of robots for workers in Germany and the United States. More research is needed to estimate the replacement of labor by robots in low-wage countries and on the extent to which automation in rich countries substitutes for offshoring production to poor countries (cf. Krenz et al., 2018).

4. Conclusion

We calculate a job creation need of 305 million between 2020 and 2030, given i) trends in population growth, ii) changes in the population's age structure, iii) changes in the gender composition of the labor force, iv) changes in age- and gender-specific labor force participation rates, and v) the desire to reach target unemployment rates of 8 percent for youths and 4 percent for adults. The job creation requirements are split unequally among country income groups. Most of these jobs will need to be created in low- to middle-income countries.

Our estimates indicate that the job creation needs due to automation by 2030 are substantial but not insurmountable. According to our preferred specification of the medium adoption of industrial robots, robots will replace 37.9 million workers in 2030 in a high-displacement scenario and 12.2 million workers in a low-displacement scenario. Manufacturing workers seem to be the most vulnerable, and the largest number of jobs that robots will substitute will accrue in Asia. Despite burgeoning automation, our calculated job displacement due to automation by 2030 is dwarfed by the job creation needs to accommodate projected demographic trends, labor force participation changes, and target unemployment rates.

A noteworthy relationship exists between the job creation needs due to demographic change and the projected job displacement due to automation: the physically demanding, routine, low-skilled entry level jobs required to meet the demand of youth working-age population growth in lower-income countries are the most susceptible to automation and automation-driven reshoring. This may present a challenge for lower-income countries if the growing youth workforce is not well educated and skilled, or performs predominantly routine tasks. From a policy perspective, investing in high-quality education of the children who are not yet in the labor force will be important to enable them to cope with competition not only from their peers in lower-income countries but also with robots in higher-income countries.

For higher-income countries with an aging labor force, the challenge will be to keep older workers healthy and in productive work. Automation could plausibly be beneficial in these countries, as the demands of an older labor force generally consist of less physically demanding and higher-skilled jobs. In these countries, providing high-quality health care, legislation that allows people to work at older ages and provides an incentive for firms to hire older workers, and potentially projects to foster collaboration between robots and older workers will be important. For example, robots can be helpful for older workers with hip problems who have to lift heavy items. Moreover, investments in lifelong learning programs are also essential to keep this group in the labor force.

Finally, it is important to stress that job creation results from a multifaceted interplay among supply-and-demand factors. Economic policies can play a role in facilitating the process of job creation by providing supportive legislation, by ensuring that workers have the required skills in a technologically fast-changing environment, and by promoting healthy aging in the workforce. Our contribution highlights some important expected shifts on the supply and demand sides for labor that might be helpful when enacting policies that influence labor markets.

As far as the potential for further research is concerned, the following areas are particularly promising and worthy of a deeper analysis. First, the potential displacement of workers in low-income countries with a young population age structure and the potential boon presented by automation for countries with aging populations might lead to further divergence in living standards between low-income and high-income countries. Thus, investigating policy measures that can help to prevent global inequality from rising will be important. Second, the inconclusive results in the literature on the differential effects of automation on women and men call for a more thorough analysis of the gender-specific impact of automation. This analysis needs to account for the changing nature of automation (away from substituting mainly routine, low-skill-intensive tasks toward substituting more nonroutine, high-skill-intensive tasks). Third, analyzing the second-order effects of global migration would be interesting because migration could change labor force participation; for example, when female labor force participation in the countries to which migrants move is higher than that in the countries from which migrants originate. Finally, while modeling job creation as a partly endogenous response to characteristics of labor supply is beyond the scope of this paper, research in this domain would be useful. For example, future research focusing on the nature of job creation in relation to the characteristics of employees and technologies available, specifically models that endogenize factors such as wages and human capital characteristics, would be valuable.

Appendix

Appendix A. Framework and data for the demographic projections

Accounting identities

In the following equations, we denote the population size by *N,* the size of the labor force by *LF,* the number of people not in the labor force by *NLF*, the number of employees by *E*, the number of unemployed by *U*, the labor force participation rate by *LFPR*, and the unemployment rate by *UR.* Using the indices *a, i, k,* and *t* to refer to age groups, countries, genders, and years, respectively, the following accounting identities hold:

$$N_{a,i,k,t} = LF_{a,i,k,t} + NLF_{a,i,k,t}, \quad \textbf{(1)}$$

$$LF_{a,i,k,t} = E_{a,i,k,t} + U_{a,i,k,t}, \quad \textbf{(2)}$$

$$LFPR_{a,i,k,t} = \frac{LF_{a,i,k,t}}{N_{a,i,k,t}}, \quad \textbf{(3)}$$

$$UR_{a,i,k,t} = \frac{U_{a,i,k,t}}{LF_{a,i,k,t}}. \quad \textbf{(4)}$$

Equation (1) states that the population comprises those who are in the labor force and those who are not. Equation (2) states that the labor force, in turn, is the sum of those who are employed and those who are not. Equations (3) and (4) define the labor force participation rate and the unemployment rate, respectively.

Following conventional standards, we refer to the age range 15–64 as the working age, which can be subdivided into 15–24 as the youth working age and 25–64 as the adult working age. In addition, we include 15+ and 25+ age ranges, as employment and unemployment data are available through the ILO for these groups. We use 8 percent as the 2030 target unemployment rate for the 15–24 age group and 4 percent as the 2030 target unemployment rate for the 25+ age group (referred to as the target youth and target adult unemployment rates throughout). If a country's unemployment rate for 2020, projected by the ILO, is lower than these targets, we use the ILO projection instead as the target 2030 unemployment rate (see Bloom and McKenna, 2015, who use this methodology).

Using Equations (1)–(4), worldwide employment at time t is given by the sum over all age groups, countries, and genders of the number of people who are currently employed:

$$E_t = \sum_a \sum_i \sum_k [(N_{a,i,k,t} \times LFPR_{a,i,k,t}) \times (1 - UR_{a,i,k,t})]. \quad \textbf{(5)}$$

The first difference of Equation (5) refers to changes in employment over time. Fluctuations in three factors—population size, labor force participation rates, and unemployment rates—drive these changes.

In our analysis we abstract from the effects of immigration and changes in the intensity of international trade. For example, the migration of families from low-wage countries to high-wage countries may be associated with increased female labor force participation. Likewise, an increase in international trade might lead to changing employment patterns in both exporting and importing countries. Finally, the investment decisions in automation may depend on the potential to substitute workers by migrants or by offshoring production. A lack of reliable data prevents us from going more into the details of the associated implications for the need to create jobs. However, we believe that, compared with the employment effects of overall general demographic shifts, the implications of migration and trade on labor force participation are of secondary importance, given that migration and current account surpluses zero out at the global level.

Data description

For the demographic analysis, we mainly rely on two datasets: the United Nations' World Population Prospects: The 2017 Revision (United Nations, 2017) for population estimates and projections and the ILO's ILOSTAT database (2018c) for labor force participation rates and unemployment rates (and projections). Regarding the World Population Prospects, we use the medium-fertility scenario projections for 2020–2030.

The following clarifications are in order: i) we assume no multiple job holding in our projections of job creation needs, ii) we do not distinguish between full- and part-time jobs, and iii) we exclude 14 countries from the analysis because they do not appear in both of the datasets relied upon. Because most of these countries are small island nations and, as a group, would account for only 1 percent of the global population in 2020, this should not affect our projections substantially. For the list of excluded countries, please refer to the notes in Table 1.[13]

Appendix B. Figures

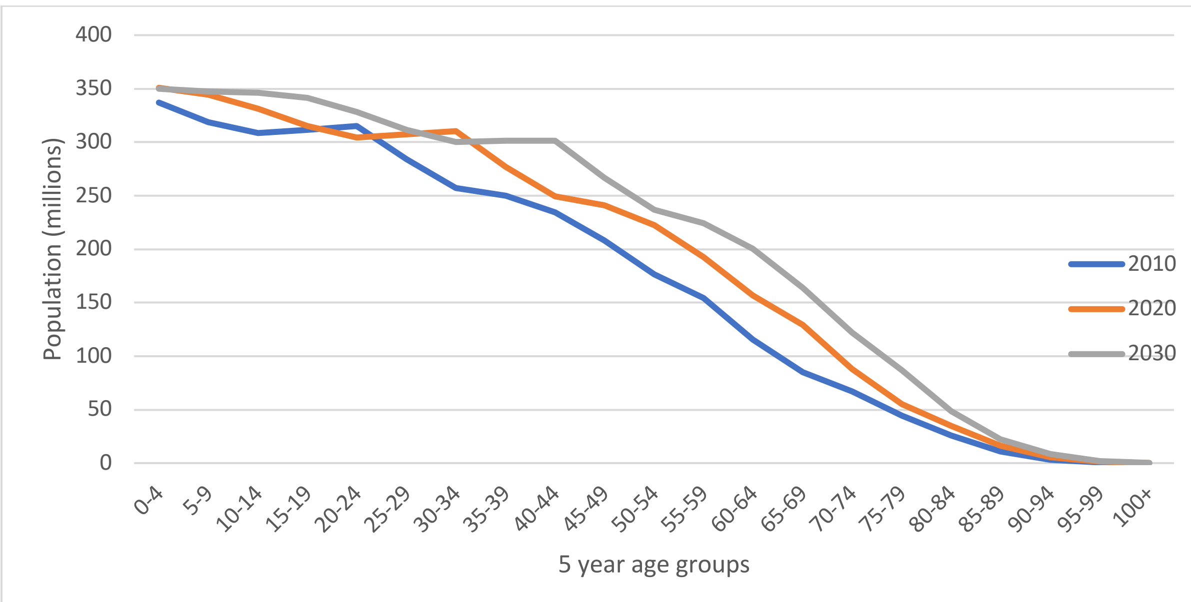

Figure B.1: Male population by age group and year
Source: Authors' work derived from United Nations (2017).

[13] Summary statistics tables present values obtained from United Nations (2017) and ILO (2018c), and the values in tables depicting estimated changes in labor force participation and employment statistics were obtained using the accounting identities outlined in Appendix A: Framework and data for the demographic projections. Unemployment rate data for the 15–64 age group were unavailable and are thus not included in the tables.

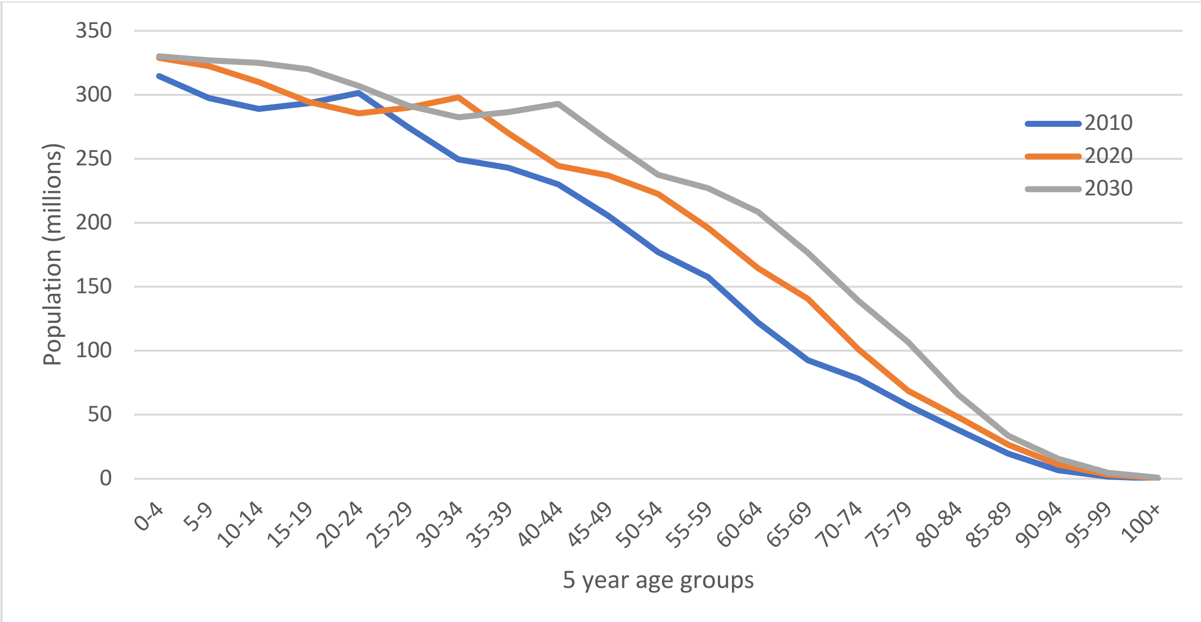

Figure B.2: Female population by age group and year
Source: Authors' work derived from United Nations (2017).

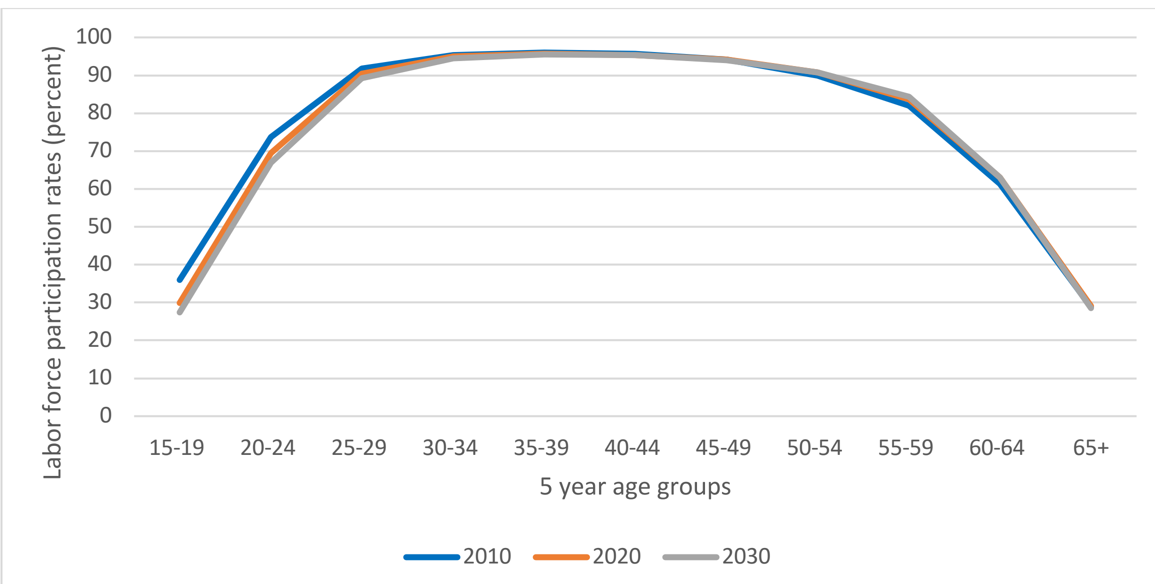

Figure B.3: Male labor force participation rates by age group and year
Source: Authors' work derived from ILO (2018c).

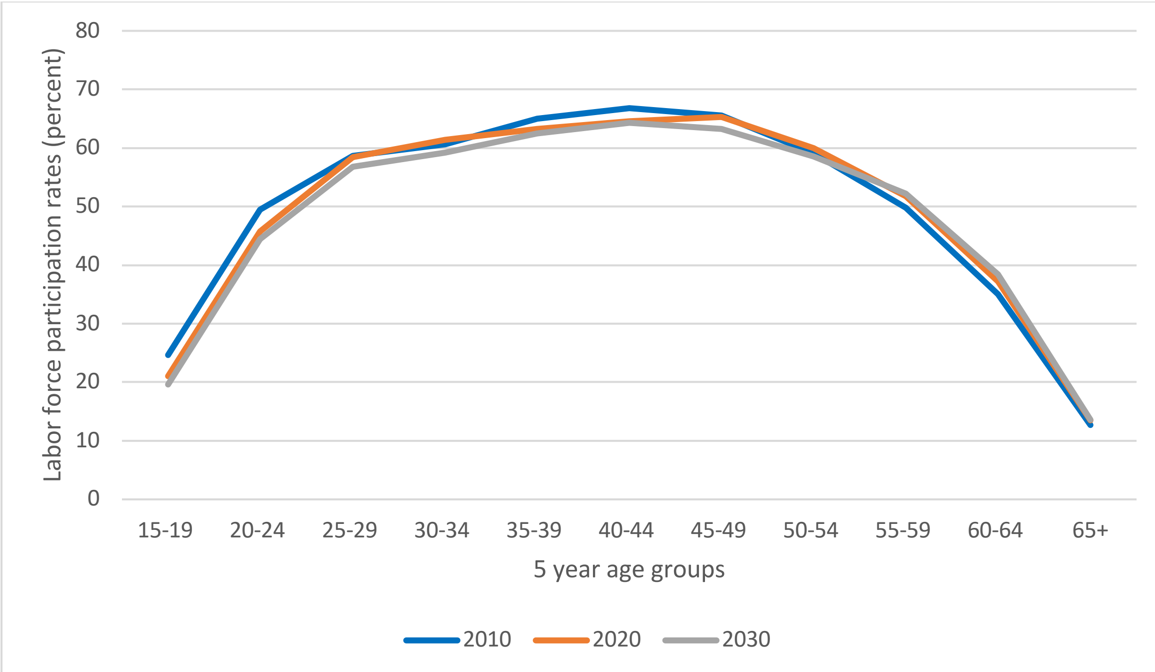

Figure B.4: Female labor force participation rates by age group and year
Source: Authors' work derived from ILO (2018c).

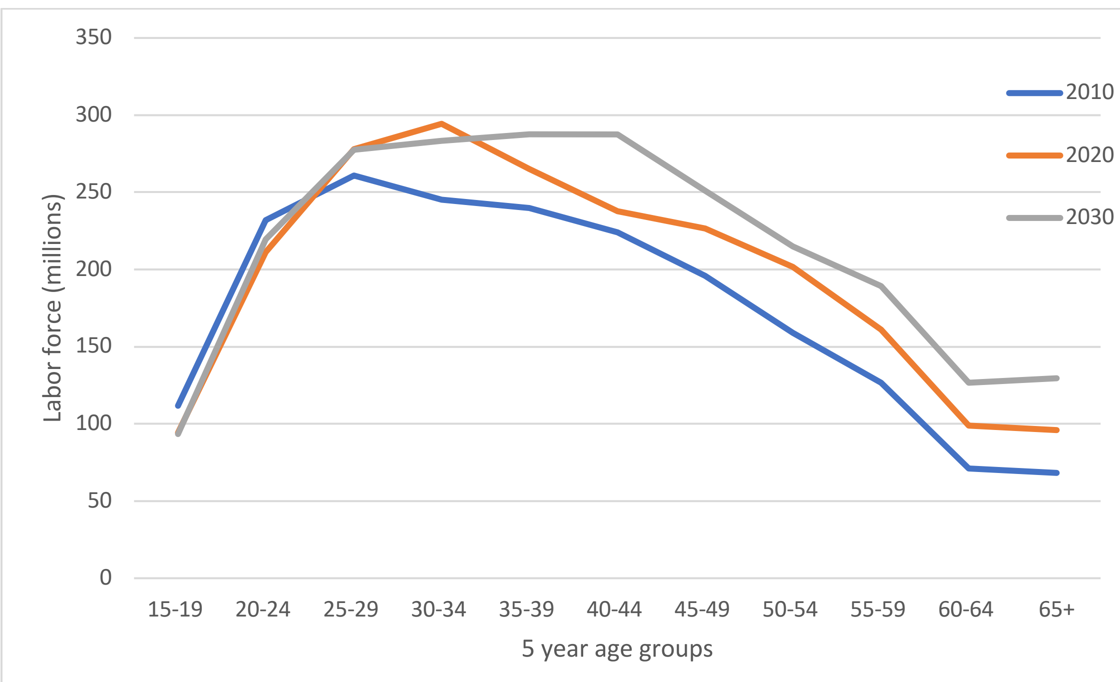

Figure B.5: Male labor force by age group and year
Source: Authors' work derived from ILO (2018c).

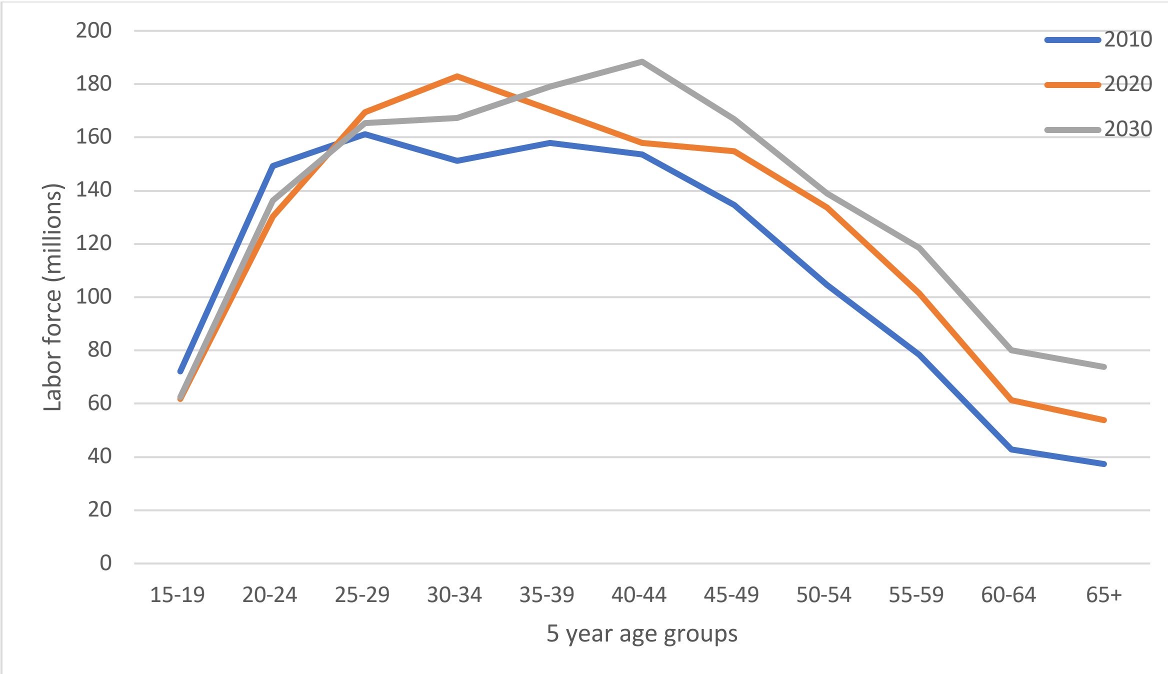

Figure B.6: Female labor force by age group and year
Source: Authors' work derived from ILO (2018c).

Appendix C. The data on automation

To project robot adoption[14] in the world and by region, we used IFR data, the only known source available that provides such information.[15] IFR reports the values of the actual stock of robots by country, region, and industry from 1993 through 2017. Moreover, the federation also has information on the deliveries of robots with the same disaggregation.

IFR calculates the stock of robots assuming that robots do not depreciate at a constant rate but go out of service after 12 years. We use these stock values for a robustness analysis and not for the benchmark specification, given that assuming an annual depreciation rate is more in line with standard economic practice (such that the robot stocks are calculated via the perpetual inventory method). Thus, our baseline projections rely on IFR's initial numbers from 1993 (or the latest available year), assume an annual depreciation rate of 10 percent, and add the number of robots that were delivered in the corresponding country in the given year. In the process, we found that several values for robot deliveries are reported as 0 in the latest years of the time series, while the stock also appears to increase. In these cases we have considered the created stock as missing. An alternative choice would have been to calculate the created stock from the changes in stocks, but this would have resulted in a noisy measure missing stock depletion values.

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[14] We understand robots as "multipurpose manipulating industrial robots," as defined by the International Organization for Standardization. This refers to "Manipulating industrial robot as defined by ISO 8373: An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications" (Graetz and Michaels, 2018; IFR, 2012).

[15] Several contributions use these data, such as Graetz and Michaels (2018), Acemoglu and Restrepo (2017a), Dauth et al. (2017), and Abeliansky and Prettner (2017).

Furthermore, we have performed two alternatives of the same calculations: one assuming that the depreciation rate is 5 percent (low-depreciation scenario) and one assuming 15 percent (high-depreciation scenario). Therefore, we have four alternatives as measures for the stock of robots. Table C.1 reports the summary statistics for the world as a whole, where "ifr" refers to the original data, "d15" to an assumed depreciation rate of 15 percent in the perpetual inventory method, "d10" to an assumed depreciation rate of 10 percent, and "d5" to an assumed depreciation rate of 5 percent. Table C.2 shows that the pairwise correlations across these different estimates are very high.

Table C.1: Summary statistics of the world stock of robots and alternative depreciation rates (for the available 1993–2017 data)

Variable	Obs.	Mean	Std. Dev.	Min	Max
ifr	25	1005560	401841.7	557516	2097552
d15	25	674659.2	229081.9	512536.2	1381582
d10	25	858375.1	307754.5	556407.4	1731532
d5	25	1160049	483874.1	557516	2372901

Note: ifr is the stock provided by default, while the corresponding variables assume a 15, 10, and 5 percent depreciation rate, respectively.

Table C.2: Correlation between the world stock of robots (for the available 1993–2017 data) and alternative depreciation rates

	ifr	d15	d10	d5
ifr	1	0.972	0.9983	0.995
d15	0.972	1	0.9832	0.9457
d10	0.9983	0.9832	1	0.9887
d5	0.995	0.9457	0.9887	1

Note: ifr is the stock provided by default, while the corresponding variables assume a 15, 10, and 5 percent depreciation rate, respectively.

If we disaggregate the stocks by countries and years and analyze the same correlations, we observe a bit more variation across stocks while the bivariate correlations remain very high (Table C.3).

Table C.3: Correlation between the country-level stock of robots as reported by the IFR and alternative depreciation rates (for the available 1993–2017 data)

	ifr	d15	d10	d5
ifr	1	0.9895	0.9902	0.9675
d15	0.9895	1	0.9919	0.9596
d10	0.9902	0.9919	1	0.9871
d5	0.9675	0.9596	0.9871	1

Note: ifr is the stock provided by default, while the corresponding variables assume a 15, 10, and 5 percent depreciation rate, respectively.

To compute the projections of employment needs, we rely on estimates from past studies on the number of jobs lost to the adoption of robots. The available estimates are from Acemoglu and

Restrepo (2017a) and Dauth et al. (2017), who examine job displacement due to robot adoption in the United States and Germany, respectively. Acemoglu and Restrepo (2017a) find that an industrial robot replaces 6.2 jobs in the United States, while Dauth et al. (2017) estimate a lower replacement level (two jobs) in Germany. Therefore, we consider the projections of Acemoglu and Restrepo (2017a) and Dauth et al. (2017) to be upper and lower bounds.

Appendix D. Robustness of the projections on automation

In this appendix, we provide several robustness checks of our baseline projections. Tables D.1–D.3 provide figures for regions of the world for the projections relying on the perpetual inventory method with 5 percent and 15 percent depreciation rates and using the raw IFR data to calculate the projected growth rates.

Table D.1: Number of jobs that industrial robots can substitute in 2030 (in millions), worldwide and by region, according to projections based on IFR (2018) data

Adoption	Displ.	World	Africa	Asia and Australia	Europe	North America	South America
low	high	24.91	0.20	17.23	4.27	3.28	0.20
	low	8.04	0.07	5.56	1.38	1.06	0.07
medium	high	46.26	0.43	37.23	5.87	5.52	0.43
	low	14.92	0.14	12.01	1.89	1.78	0.14
high	high	83.53	0.86	77.03	8.00	9.11	0.86
	low	26.94	0.28	24.85	2.58	2.94	0.28

Note: The figures refer to the number of workers (in millions) who can be substituted by industrial robots in the year 2030, according to a combination of three scenarios in terms of the adoption of robots and two scenarios in terms of the potential displacement of workers by robots. "Adoption" refers to the calculation of projected industrial robots in the year 2030. The "medium" variant projects the average growth rate in the number of industrial robots in 2010–2017 forward to 2030. The "low" variant assumes that the projected growth rate drops by 50 percent, whereas the "high" variant assumes that the projected growth rate increases by 50 percent. "Displ." refers to the two displacement scenarios. The "high" variant relies on the estimates of Acemoglu and Restrepo (2017a), wherein one industrial robot substitutes for 6.2 workers in manufacturing in the United States. The "low" variant refers to the estimates of Dauth et al. (2017), wherein one industrial robot substitutes for two manufacturing workers in Germany.

Table D.2: Number of jobs that industrial robots can substitute in 2030 (in millions), worldwide and by region, according to projections based on the perpetual inventory method and an assumed 5 percent depreciation rate of robots (baseline data used for the perpetual inventory method: IFR, 2018)

Adoption	Displ.	World	Africa	Asia and Australia	Europe	North America	South America
low	high	26.16	0.06	16.61	5.16	3.62	0.20
	low	8.44	0.02	5.36	1.66	1.17	0.07
medium	high	45.39	0.13	30.24	7.56	6.35	0.45
	low	14.64	0.04	9.76	2.44	2.05	0.15
high	high	77.01	0.28	53.62	10.96	10.90	0.96

	low	24.84	0.09	17.30	3.54	3.52	0.31

Note: See Table D.1.

Table D.3: Number of jobs that industrial robots can substitute in 2030 (in millions), worldwide and by region, according to projections based on the perpetual inventory method and an assumed 15 percent depreciation rate of robots (baseline data used for the perpetual inventory method: IFR, 2018)

Adoption	Displ.	World	Africa	Asia and Australia	Europe	North America	South America
low	high	17.86	0.04	12.49	2.82	2.29	0.12
	low	5.76	0.01	4.03	0.91	0.74	0.04
medium	high	35.82	0.07	27.83	4.30	4.35	0.25
	low	11.56	0.02	8.98	1.39	1.40	0.08
high	high	69.33	0.13	59.20	6.45	8.01	0.52
	low	22.36	0.04	19.10	2.08	2.59	0.17

Note: See Table D.1.

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