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The Automatisation Challenge Meets the Demographic Challenge: In Need of Higher Productivity Growth

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Jobs & Incomes in the Dawning Era of Intelligence Robots

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DG ECFIN's Fellowship Initiative 2018-2019 "The Productivity Challenge: Jobs and Incomes in the Dawning Era of Intelligent Robots" has solicited contributions examining current and possible future productivity developments in Europe. In view of possible hysteresis effects after the crisis and in the general context of ageing populations and globalisation, the aim has been to re-examine the ongoing trends and drivers and to identify policies to tap fully the potential for inclusive productivity growth. The fellowships have been awarded to prominent scholars in the field to interact with staff in ECFIN and other Commission colleagues, and to prepare final reports on specific research questions within this general topic.

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The Automatisation Challenge Meets the Demographic Challenge:

In Need of Higher Productivity Growth

Sandra Leitner and Robert Stehrer

Abstract

The future of employment and labour demand growth in the dawning era of intelligent robots and other new technologies is heavily debated. This paper argues that this discussion needs to be complemented by a second trend which has been unfolding in Europe for some time, namely the demographic decline. Various demographic scenarios for many EU countries point towards a significant decline in the working-age population in the near future which puts the functioning of labour markets at risk as labour shortages become increasingly more likely and subsequently threaten economic growth. In this context, this paper gives an overview of recent trends in the growth of real value added, labour productivity and employment as well as of demographic scenarios. Based on these trends, the hypothetical increase of labour productivity growth which would be required to keep real GDP growth at its current level, despite the projected reduction in the workforce, is calculated. Results show that the hypothetical labour productivity growth rate required is about one percentage point higher than the actual growth rate, suggesting that the current labour productivity growth rate in the EU needs to more than double. A complementary econometric analysis shows that even though robots exhibit a positive impact on labour productivity growth, this is not (yet) strong enough to close the gap between the recent and the hypothetical labour productivity trend growth rate which would be required.

JEL Classification: J11, O33, O47.

Keywords: Robotisation, ICT capital, productivity, demography.

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1. INTRODUCTION

Recently, two significant but opposing trends could be observed. First, the emergence and rapid spread of new technologies, which is expected to have strong negative impacts on labour demand according to some of the literature, particularly on less qualified workers whose jobs comprise, to a large degree, of predictable and routine cognitive tasks which can easily be replicated by machines. For instance, the seminal study by Frey and Osborne (2013) suggests that about 47% of jobs in the US are at high risk of automation. However, more recent studies present less alarming numbers: Arntz et al. (2016) used a more careful methodology and estimated that about 9% of jobs in the OECD are at risk of automation. In a more recent report, OECD (2019) states that 14% of jobs are at high risk of automation (with large variations between countries), that 32% of jobs could be radically transformed in the medium-term and draws important policy conclusions from the dawning era of these new technologies.[1] Furthermore, in a report for the European Commission, Servoz (2019) emphasises the role of information technology (IT) and artificial intelligence (AI) for the future of work. While acknowledging the potential impacts on future jobs and skills needs, and the societal transformations in general, this report also stresses the job creation potential of these new technologies. In addition to the wide variety of expected impacts on employment in most countries, the time interval between job destruction or displacement and job creation and the difficulty in predicting these evolutions over time is acknowledged. The diffusion of new technologies is however generally expected to happen at a slower pace and to take place at different speeds across industries and countries. The process might therefore turn out to be less disruptive than the sheer numbers suggest.[2]

Second, in many European countries, demographic developments can be observed which, in the medium to long-term, result in a decline in the overall population, and an even stronger decline in the working-age population (aged 15-64). As shown in Figure 1.1, Eurostat's baseline scenario for Europe predicts that by 2050 its population aged 20-64 will decline by about 10%, while its total population will still increase by about 4%, leading to an overall ageing of the European population. However, these developments are uneven across EU countries: for instance, for Central and East European (EU-CEE) countries, Eurostat's baseline scenario predicts a decline in the working-age population aged 20-64 by 2050 of about 30%. The ensuing potential labour shortages and the potential subsequent slowdown in GDP growth have become major policy concerns (see Fotakis, and Peschner, 2015; Boussemart and Godet, 2018; Stehrer and Leitner, 2019; Leitner, Grievenson, and Stehrer, 2019).[3] Similarly, EBRD (2018) points towards the challenges of rapid demographic change in emerging Europe.

Against this backdrop, this paper points to some recent demographic trends to depict trends in labour supply, on the one hand, and (labour) productivity and real value added growth on the other, which together determine labour demand. In so doing, the paper emphasises the need to increase (labour) productivity growth in order to circumvent potential labour market shortages, which become increasingly more likely in view of the ongoing demographic decline, and the subsequent reduction in

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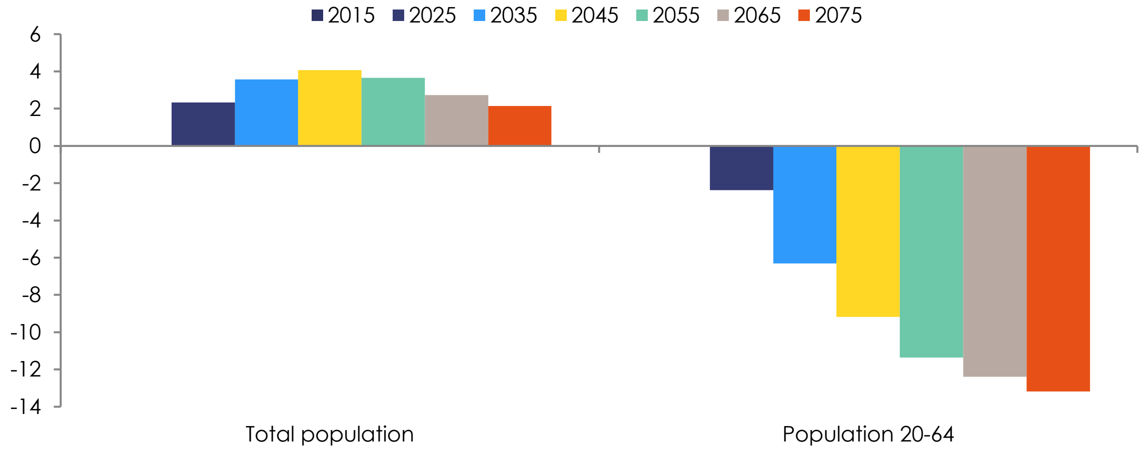
1 Other recent OECD publications include Arntz and Zierahn (2016), Berger and Frey (2016), and Nedelkoska, L. and G. Quintini (2018).

2 It is however argued that new technologies lead to a change in the structure of employment and the tasks to be performed. Thus, while new technologies will not destroy a large numbers of jobs, they will lead to rising inequality and the need to (re-)train especially low qualified workers. These aspects are however less relevant for this paper.

3 Also the above cited OECD report points towards the ageing of populations stating that in 2050 the number of 65+ year-olds people per 100 people of working age in 2050 is 53 (compared to 28 in 2015).

GDP growth. Section 2 presents some stylised trends and sketches a simple model to discuss these trends. In Section 3, some demographic scenarios are discussed which provide information as to the extent to which (labour) productivity needs to increase in order to sustain current trends in GDP growth. Section 4 then provides an econometric analysis to show whether and to what extent robotisation and investment in ICT can help close the gap between the actual and the needed trend growth rates of (labour) productivity. Finally, Section 5 summarises and concludes.

Figure 1.1 **Demographic trends in the EU-28, in % of the population in 2015**



Note: Eurostat demographic forecasts (baseline scenario).

Source: Eurostat; own calculations.

2. STYLISED FACTS AND THEORETICAL CONSIDERATIONS

In the following, trends in total and working-age populations, activity rates, labour productivity and real value added growth are presented. Based on these stylised trends, a simple model is outlined which explicitly describes the implications of a declining, or negative growth rate of labour supply for GDP growth. In a simple neoclassical growth model (Solow model), long-term GDP growth is given by the rate of technical (labour augmenting) progress and population growth. However, the standard growth model does not distinguish between total population and working-age population growth nor does it consider changes in activity rates (i.e. the share of persons of the working age population active in the labour market by either being employed or searching for a job).[4] Therefore, in the following theoretical outline, labour supply and demand are more carefully distinguished.[5].

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4 See Appendix A for an outline in the Solow framework.

5 For recent contributions on the effects of automatisation on growth and employment in such models see, e.g. Geiger et al. (2018) and Prettner (2018).

2.1. STYLISED FACTS

The stylised trends between 2002 and 2016 for key demographic and economic variables are reported in Table 2.1. The key issues can be seen when considering the EU-28. First, the working-age population (aged 20-64) has grown at a lower rate than total population (0.18% compared to 0.29%). This is also the case for most individual EU countries. In some EU countries – particularly the EU-CEE countries – the working-age population has even declined over the period considered. Second, in most EU countries, employment growth rates were positive and larger than working-age population growth rates. For instance, in the EU-28, employment has grown at a rate of 0.54% per annum, whereas the working-age population has only grown at 0.18% per annum. This shows that labour productivity growth was lower than growth in real value added (0.86% compared to 1.41% in the EU-28). Qualitatively, this also holds when labour productivity growth is measured in terms of hours worked. Finally, throughout the EU, activity rates are already at relatively high levels: 78% in the EU-28 and ranging from 71% in Croatia to 87% in Sweden.

Table 2.1 **Selected demographic and economic trends, 2002-2016**

	Demographics		Economic variables				
	Total population	Working age population	Employment	Real value added	Labour productivity (employed persons)	Labour productivity (hours worked)	Activity rates (in %)*
EU28	0.29	0.18	0.54	1.41	0.86	1.08	78
AT	0.56	0.59	0.97	1.58	0.58	1.20	80
BE	0.63	0.56	0.79	1.50	0.69	0.85	74
BG	-0.85	-0.91	0.60	3.64	2.96	2.99	76
CY	1.29	1.72	1.41	1.90	0.47	0.99	80
CZ	0.21	0.01	0.62	2.87	2.17	2.29	81
DE	0.02	-0.17	0.67	1.35	0.65	1.01	82
DK	0.45	0.11	0.31	1.06	0.74	1.02	81
EE	-0.35	-0.38	0.53	3.55	2.81	3.19	83
EL	-0.04	-0.29	-0.23	-0.20	-0.02	0.15	74
ES	0.85	0.74	0.82	1.49	0.68	0.95	79
FI	0.38	0.05	0.56	1.12	0.51	0.85	81
FR	0.59	0.36	0.45	1.22	0.77	0.83	78
HR	-0.21	-0.22	-0.91	1.65	0.51	1.15	71
HU	-0.25	-0.24	0.45	2.14	1.64	0.82	76
IE	1.40	1.43	1.34	4.96	3.36	3.86	78
IT	0.39	0.12	0.43	0.13	-0.31	0.10	70
LT	-1.26	-1.08	0.08	4.06	3.78	3.74	82
LU	1.87	2.11	2.78	2.57	-0.24	0.08	76
LV	-1.17	-1.14	-0.26	3.65	3.77	4.10	82
MT	1.02	1.18	2.33				76
NL	0.41	0.13	0.53	1.35	0.81	0.89	82
PL	-0.05	0.31	0.88	3.81	2.87	3.04	75
PT	-0.01	-0.14	-0.39	0.46	0.85	0.92	81
RO	-0.82	-0.82	-1.24	4.01	5.15	5.35	72
SE	0.74	0.59	0.84	2.24	1.35	1.39	87
SI	0.23	0.07	0.46	2.29	1.76	2.04	79
SK	0.07	0.40	0.97	4.03	2.94	3.25	77
UK	0.69	0.62	0.92	1.71	0.77	0.87	81

Source: Eurostat, own calculations.

2.2. A SIMPLE THEORETICAL CONSIDERATION

2.2.1. Labour supply

The effects of a change in population growth can be seen by considering a simple Solow growth model and is sketched in the Appendix. Here a slightly more elaborate model is sketched. Let us denote the growth rate of the working-age population[6] at time t by n_t and working age population (in number of persons) at time t by N_t. Thus, the working-age population changes according to

$$N_t = N_{t-1}(1 + n_t) \tag{2.1}$$

Given observable demographic trends, working-age population growth can also be negative, i.e. $n_t < 0$. However, such a demography-induced decrease in the size of the working-age population could be compensated by rising activity rates (for instance, due to an increase in female labour force participation). Denoting the share of active persons in the total working-age population at time t with a_t, labour supply S_t develops according to

$$S_t = a_t N_t = a_t N_{t-1}(1 + n_t) \tag{2.2}$$

This reflects that a negative trend in the working-age population might be counteracted by increasing activity rates to keep labour supply growing or at least constant. However, activity rates cannot increase beyond a certain threshold. An activity rate of one would imply that all persons in the working-age population would be active in the labour market, which is impossible. However, a somewhat lower bound might realistically be achievable. For example, according to the Lisbon target, the share of active persons in the working-age population (defined as aged 20-64) should be 75%. Assuming that the activity rate a_t converges to the target $\bar{a}$ the dynamics might be modelled as a logistic function

$$a_t = a_{t-1} + \delta a_{t-1}\left(1 - \frac{a_{t-1}}{\bar{a}}\right) \tag{2.3}$$

with δ denoting the (unimpeded) growth rate. The actual growth rate of the activity rate is given by $\frac{a_t - a_{t-1}}{a_{t-1}} = \delta\left(1 - \frac{a_{t-1}}{\bar{a}}\right)$. Using this, the workforce develops according to

$$S_t = \left[a_{t-1} + \delta a_{t-1}\left(1 - \frac{a_{t-1}}{\bar{a}}\right)\right] N_{t-1}(1 + n_t) \tag{2.4}$$

Rewriting the development of the workforce shows that

$$\Delta S_t = S_t - S_{t-1} = a_t N_t - a_{t-1}N_{t-1} = a_t N_{t-1}(1 + n_t) - a_{t-1}N_{t-1} = N_{t-1}[\Delta a_t + n_t a_t] \tag{2.5}$$

so that the growth rate of the workforce is approximately given by

$$\frac{\Delta S_t}{S_t} = \frac{N_{t-1}}{N_t}\left[\frac{\Delta a_t}{a_t} + n_t\right] = \frac{1}{1+n_t}\left[\frac{\Delta a_t}{a_t} + n_t\right] \approx \frac{\Delta a_t}{a_t} + n_t \tag{2.6}$$

6 As later the Eurostat demographic scenarios are used the growth rate of the working age population is modelled time variant.

for small growth rates of the working-age population n_t (as $\frac{1}{1+n_t} \approx 1$). Thus, labour supply is growing as long as $\frac{\Delta a_t}{a_t} > -n_t$, i.e. the growth rate of the activity rate has to be larger than the negative of the growth rate of the working-age population. This is of course always the case if $n_t > 0$ (assuming convergence of the activity rate to the target level $\bar{a}$ from below, implying $\frac{\Delta a_t}{a_t} > 0$). However if the growth rate of the working-age population is negative this condition can easily be violated, particularly as $\frac{\Delta a_t}{a_t} \rightarrow 0$ if an economy reaches the threshold level). Thus, in case of a negative growth rate of the working-age population, potential small increases in the activity rates might not be sufficient to counteract the demographic decline.

2.2.2. Labour demand

By definition, total economy employment growth is the difference between (real) GDP growth and labour productivity growth (e.g. real GDP per employed person or per hour worked), i.e. formally

$$e_t = y_t - \varphi_t \tag{2.7}$$

where e_t denotes the employment growth at time t, y_t is real GDP growth and $\varphi_t$is labour productivity growth. There is a simple interpretation of this: If GDP grows faster than labour productivity, employment is growing. Or, if GDP grows at the same rate as labour productivity there would be no increase in demand for labour ('jobless growth'), irrespective of the growth of the total economy.[7]

2.2.3. Steady-state considerations

Based on this simple framework sketched above it is instructive to study the balanced growth path in this simple model. A balanced growth path would require that labour supply and labour demand grow at equal rates, i.e.

$$\frac{\Delta a_t}{a_t} + n_t = y_t - \varphi_t \tag{2.9}$$

Assuming that $\Delta a_t \rightarrow 0$ (as labour participation threshold is reached) and constant long-term growth rates, the equation simplifies to

$$y = n + \varphi \tag{2.10}$$

i.e. GDP growth depends on the growth rate of the working-age population plus the growth rate of labour productivity.[8]

There are various ways to look at this equation. In the context of this paper the growth of the working-age population (and the labour supply assuming that the economy already operates at the activity rate threshold) is exogenous. Then, an economy's real GDP growth is determined by the growth of the

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[7] This relation here is stated as an accounting formula. Of course, GDP growth and productivity growth are likely to be dependent on each other. E.g. the Kaldor-Verdoorn law would argue that productivity growth is driven by output growth; neoclassical theorising would suggest that productivity growth (in the steady state) drives output growth.

[8] The similarity with the Solow growth model where GDP growth equals population growth plus exogenous technical change minus the depreciation rate which is not considered here (see Appendix), should be noted.

working-age population and (total economy) labour productivity growth. If the former becomes negative due to demographic trends, the growth rate of real GDP becomes lower as well.

From above, labour supply (after reaching the activity threshold) is growing at the rate of working-age population growth, i.e. $s_t = n_t$, whereas labour demand is growing at $e_t = y_t - \varphi_t$. Combining these two equations and setting labour demand growth equal to labour supply growth yields

$$y_t = n_t + \varphi_t \tag{2.11}$$

First, for a given working-age population growth rate n_t and a growth in labour productivity φ_t the growth rate of real GDP is determined. This implies that if $n_t < 0$, real GDP growth becomes lower if not counteracted by higher productivity growth. Eventually, that might be counteracted by stronger productivity growth (driven by TFP growth, new technologies, capital investments, etc.) which is the focus of this paper.[9]

3. IMPLICATIONS FOR LONGER-TERM GROWTH PROSPECTS IN THE FUTURE

3.1. TRENDS IN LABOUR SUPPLY

As outlined above, labour supply depends on the growth of the working-age population and changes in the activity rates. As concerns the working-age population, Table 3.1 reports the 6 different scenarios of expected developments provided by Eurostat's demographic forecasts (in terms of average growth rates over the period 2015 (start of the projection period) to 2045).

As can be seen, projected working-age population trends are negative for the majority of EU countries, but remain positive for some EU countries, which is mostly driven by immigration. Further, for most EU countries, the projected growth rates are even lower than those reported for the past (see Table 2.1 above). For instance, for the EU-28, the projected working-age population growth rate in the baseline scenario is -0.32% per annum compared to the past growth rate of 0.18% per annum reported above. Furthermore, Table 2.1 above pointed to relatively high activity rates across EU countries. Though activity rates might still increase to some extent, there is little potential left to strongly counter projected population trends. Thus, there is a strong indication that labour supply will either decline in many EU countries (including the EU-28 as a whole) or remain at least stable.

[9] So far this outline assumes that these variables are independent from each other; in Appendix A.2 a generalisation in this respect is discussed.

Table 3.1 **Demographic trends 2015-2045 (growth rates in %), working-age population 20-64**

		Natural change			Migration[1)]	
	Baseline	Low fertility	Low mortality	No	Low	High
EU28	-0.32	-0.49	-0.32	-0.73	-0.45	-0.19
AT	0.21	0.07	0.22	-0.87	-0.11	0.51
BE	0.21	0.05	0.22	-0.50	-0.01	0.42
BG	-1.32	-1.50	-1.31	-1.09	-1.24	-1.39
CY	0.25	0.11	0.26	-0.40	0.05	0.45
CZ	-0.55	-0.73	-0.55	-0.88	-0.66	-0.45
DE	-0.33	-0.48	-0.32	-1.05	-0.55	-0.11
DK	0.30	0.13	0.30	-0.44	0.07	0.51
EE	-0.52	-0.70	-0.51	-0.71	-0.58	-0.46
EL	-1.21	-1.36	-1.20	-1.03	-1.15	-1.27
ES	-0.62	-0.78	-0.61	-0.97	-0.73	-0.51
FI	-0.13	-0.30	-0.13	-0.52	-0.25	-0.01
FR	-0.00	-0.20	-0.00	-0.21	-0.07	0.06
HR	-0.78	-0.94	-0.77	-0.87	-0.81	-0.75
HU	-0.66	-0.83	-0.65	-0.94	-0.75	-0.57
IE	0.18	-0.01	0.19	-0.01	0.12	0.24
IT	-0.62	-0.76	-0.62	-1.21	-0.81	-0.45
LT	-1.83	-2.06	-1.82	-0.74	-1.42	-2.28
LU	1.25	1.12	1.25	-0.65	0.72	1.71
LV	-1.42	-1.64	-1.41	-0.76	-1.19	-1.67
MT	0.21	0.06	0.21	-0.68	-0.06	0.46
NL	0.06	-0.11	0.06	-0.53	-0.13	0.24
PL	-0.82	-0.99	-0.81	-0.81	-0.82	-0.82
PT	-0.92	-1.07	-0.92	-1.10	-0.98	-0.87
RO	-1.17	-1.36	-1.16	-0.80	-1.04	-1.30
SE	0.60	0.43	0.60	-0.27	0.33	0.85
SI	-0.63	-0.79	-0.62	-1.00	-0.75	-0.51
SK	-0.65	-0.81	-0.64	-0.82	-0.70	-0.59
UK	0.29	0.11	0.30	-0.29	0.11	0.47

1) Migration scenarios are taken from Eurostat.

Source: Eurostat demographic forecasts; own calculations.

3.2. LABOUR-CONSTRAINED GROWTH OR TECHNOLOGICAL BOOST?

What are the implications of these projected demographic trends for growth? Assuming that the trend growth rate in labour productivity and real value added are sustained, labour demand will exceed (the stable or even declining) labour supply sooner or later. In such a case, GDP growth might be severely constrained by labour shortages, which poses a significant risk to these countries' medium to long-term growth prospects (Fotakis and Peschner, 2015). For instance, Stehrer and Leitner (2019) calculate a 'tipping point' defined as the year when – based on the assumption that recent trends continue – labour demand would exceed labour supply in the European economies. Based on various scenarios and robustness checks, this study concludes that such a tipping point is imminent and could be expected as early as in the 2020s for many EU-CEE countries and in the 2030s for many other EU countries.

An alternative consideration is to determine the labour productivity growth rates that are needed to keep GDP growth at a certain level. Thus, one can calculate

$$\varphi^{hyp} = y - n$$

where y denotes a pre-specified growth rate of real value added (e.g. the trend growth rates reported in Table 3.2) and n is the growth rate of the working-age population taken from Eurostat's demographic scenarios. If we assume that each country maintains its labour productivity trend growth rate as well, it is possible to calculate the additional labour productivity growth (in percentage points) needed to maintain the growth of real value added (given trends in labour productivity and trends in the demographic scenarios), i.e. $\varphi^{\text{needed}} = \varphi^{\text{hyp}} - \varphi^{\text{trend}}$. The results from this exercise are reported in Table 3.2 (Figure 3.1 shows a boxplot of these results). As some countries experienced negative GDP and/or labour productivity growth in the recent past, we replaced the values for real value added and labour productivity growth with the EU-28 growth rates. In addition to the demographic scenarios, we include a calculation assuming no change in the working-age population (i.e. growth rate of zero).

Table 3.2 **Hypothetical growth rates of labour productivity needed to keep real GDP growth at current trends (2015-2045)**

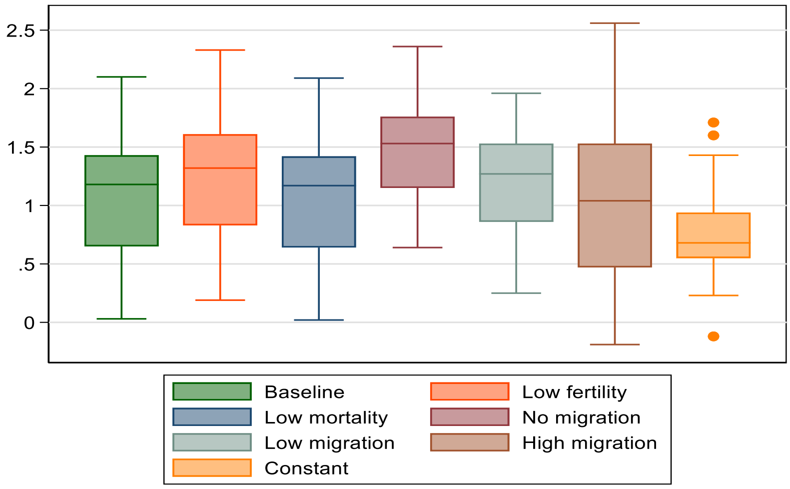
	Constant working-age population	Baseline	Low fertility	Low mortality	No migration	Low migration	High migration
EU28	0.56	0.88	1.05	0.87	1.29	1.01	0.75
AT	1.00	0.78	0.93	0.78	1.86	1.10	0.49
BE	0.81	0.59	0.76	0.59	1.31	0.81	0.38
BG	0.68	1.99	2.18	1.98	1.77	1.92	2.07
CY	1.43	1.18	1.32	1.17	1.83	1.38	0.98
CZ	0.70	1.25	1.42	1.24	1.58	1.36	1.15
DE	0.70	1.03	1.18	1.02	1.75	1.25	0.81
DK	0.32	0.03	0.19	0.02	0.76	0.25	-0.19
EE	0.74	1.26	1.44	1.25	1.45	1.32	1.19
EL	0.55	1.76	1.91	1.75	1.58	1.70	1.82
ES	0.81	1.43	1.59	1.42	1.78	1.54	1.32
FI	0.61	0.74	0.91	0.73	1.12	0.86	0.62
FR	0.46	0.46	0.66	0.46	0.67	0.53	0.40
HR	1.14	1.92	2.08	1.92	2.02	1.96	1.89
HU	0.50	1.16	1.33	1.15	1.44	1.25	1.07
IE	1.60	1.42	1.61	1.42	1.61	1.48	1.36
IT	0.55	1.18	1.32	1.17	1.76	1.36	1.00
LT	0.28	2.10	2.33	2.09	1.02	1.70	2.56
LU	1.71	0.47	0.60	0.46	2.36	0.99	0.01
LV	-0.12	1.30	1.52	1.29	0.64	1.06	1.55
MT	0.55	0.34	0.49	0.34	1.23	0.62	0.09
NL	0.55	0.49	0.65	0.48	1.08	0.67	0.31
PL	0.94	1.76	1.92	1.75	1.75	1.76	1.76
PT	0.55	1.48	1.62	1.47	1.65	1.53	1.42
RO	0.23	1.40	1.59	1.39	1.03	1.27	1.53
SE	0.88	0.28	0.46	0.28	1.15	0.55	0.04
SI	0.53	1.16	1.32	1.15	1.53	1.28	1.04
SK	1.09	1.74	1.91	1.73	1.91	1.80	1.69
UK	0.94	0.65	0.83	0.64	1.23	0.83	0.47
Mean	0.73	1.11	1.28	1.11	1.45	1.21	1.02
Median	0.69	1.18	1.33	1.17	1.56	1.27	1.06

Note: For Greece, Italy and Luxembourg trend growth rates for EU-28 has been assumed.

Source: own calculations.

These calculations show that in order to keep real GDP growth at current trend levels, labour productivity growth would have to increase by about 0.9 percentage points for the EU-28 according to the baseline scenario. Of course there are large country differences which range from very small values in Denmark to more than one and even two percentage points as in Lithuania. Depending on the scenario considered, the hypothetical increase in labour productivity required ranges between 0.7 and 1.5 percentage points on average, depending on the specific scenario considered. Even in the case of constant population, labour productivity growth would have to increase by about 0.5 percentage points in the EU-28 (and 0.7 percentage points on average) just to sustain the current trends in GDP growth. These considerations suggest that in view of the projected adverse trend in the working-age population developments, labour productivity growth needs to increase by about 1 percentage point (on average) to keep real GDP growth at its current level. On average, this is equivalent to a doubling of the labour productivity growth rates (though these numbers differ across countries).

Figure 3.1 **Boxplot of the hypothetically needed increase in labour productivity growth rates across EU countries for various demographic scenarios (in percentage points)**



Source: own calculations (based on Table 3.2).

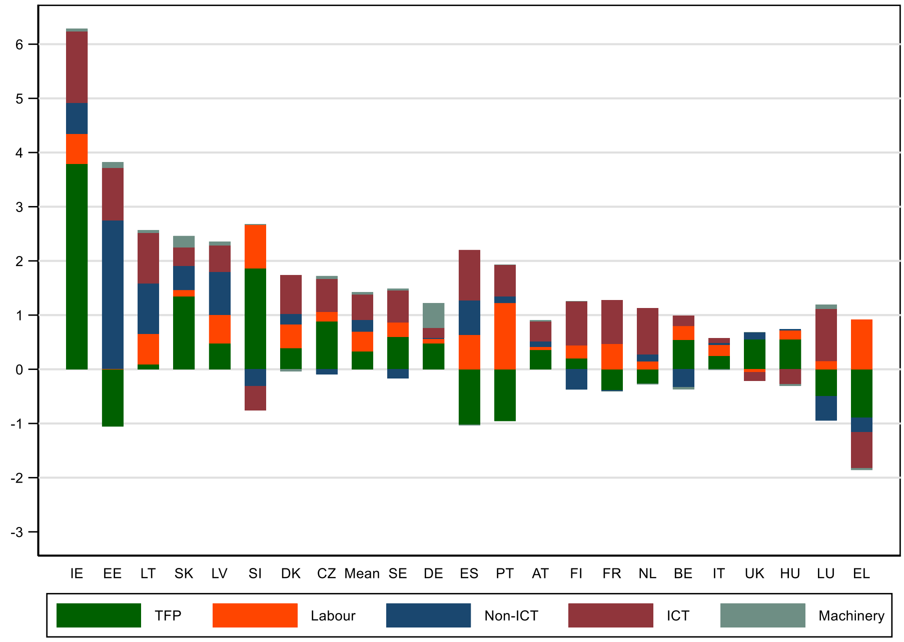
4. THE LABOUR PRODUCTIVITY POTENTIAL OF ICT CAPITAL FORMATION AND ROBOTS

In this section we analyse the impacts of gross fixed capital formation and the use of robots on labour productivity in the EU. Capital investment and automation are vital in this context, as they are considered to help spur labour productivity growth (despite their potential labour-shedding effects) and therefore circumvent the slowdown in GDP per capita growth which results from the projected demographic decline.

4.1. GROWTH ACCOUNTING RESULTS

To do so, in a first exercise we calculate the contributions of ICT and machinery (which should include robots) to the growth rates of labour productivity using a growth accounting framework. Specifically, we use the results of the EU KLEMS 2019 release (see Stehrer, et al. 2019) and decompose value added per hours worked growth into total factor productivity growth, growth in labour composition, and growth of non-ICT capital services (excluding machinery), ICT capital services and machinery. The latter is considered separately as new technologies might be embodied in the instalment of new machines.

Figure 4.1 **Composition of labour productivity growth rates, 2011-2017**



Source: EU KLEMS Release 2019; own calculations.

The (unweighted) average labour productivity growth (over the 22 countries for which such an analysis can be undertaken) has at about 1.4%. The preliminary results from the EU KLEMS release 2019 suggest that over the period 2011-2017 the contributions to value added growth are almost 25% for TFP growth, about 25% for labour composition, 19% for non-ICT capital (of which about 3% for Machinery) and the small rest of only about 30% from ICT (hardware and software). However, these magnitudes strongly differ across countries and time periods considered.[10]

The important point from this exercise is as follows: These numbers suggest that – holding other contributions equal – in order to increase labour productivity growth by 1 percentage point the contribution of ICT capital would have to increase by a factor of about three.[11]

10 Atkinson (2018) provides a detailed comparison between Europe and the US.

11 This does not take into account that an increase in labour productivity growth is also likely to increase real value added growth, such that the net effect on employment growth in light of the demographic declines of the labour supply might be limited.

4.2. REGRESSION ANALYSIS

4.2.1. Methodological approach

In the following, the role of capital investment – and the implementation of new technologies embodied in capital – for the rate of labour augmenting technical change is determined econometrically.

The following empirical specification is based on the following production function:[12]

$$Y_{it} = AK_{it}^{\alpha}L_{it}^{\beta}, \quad (4.1)$$

where Y_{it} refers to value added in country i at time t, K_{it} refers to capital while L_{it} refers to labour. We assume that this relationship can be approximated by a Cobb-Douglas production function. The above production function can be rewritten in log-form as follows:

$$y_{it} = a + \alpha k_{it} + \beta l_{it}, \quad (4.2)$$

where y, a, k and l are the logs of Y, A, K and L respectively. With labour productivity as the dependent variable – that is, subtracting l from y – equation (4.2) becomes:

$$y_{it} - l_{it} = a + \alpha(k_{it} - l_{it}) + (\alpha + \beta - 1)l_{it}. \quad (4.3)$$

As concerns k, the density of industrial robots (RD) is also taken into account, which is defined as the (log of the) number of robots per employee. Furthermore, the coefficient for l_{it} is indicative of the nature of scales in production and equal to 0 in the case of constant returns to scale (i.e. when $\alpha + \beta - 1 = 0$) but positive (negative) in the case of increasing (decreasing) returns to scale.

Finally, this leads to the following empirical specification for the regression analysis:

$$\Delta lnlp_c = a + \sum_k \alpha_k \Delta lnj_{k,c} + \theta l_c + \gamma controls_c + \varepsilon_c, \quad (4.4)$$

where $\Delta lnlp_c$ refers to the growth rate of labour productivity in country c and $\Delta lnj_{k,c}$ refers to the growth rates of k types of capital including industrial robots, ICT and non-ICT capital. Since industrial robots are part of the non-ICT capital measure, non-ICT capital is further split up into a measure which captures industrial robots to some degree, on the one hand, and other types of non-ICT capital on the other. ε_c is the error term. Furthermore, l_c refers to the growth rate of the total number of persons engaged (with $\theta = \alpha + \beta - 1$) while $controls_c$ include other control variables such as a dummy for countries located in Central and Eastern Europe. All variables are expressed in intensive form as either in terms of employees or, in an additional consistency check, in total hours worked. Given the interest in overall average effects, equation (4.4) is estimated as a cross-section based on average annual growth rates. All in all, four different time periods are considered to also explicitly take the crisis period into account, which led to a plunge in labour productivity growth and investment activities: (i) the *total period* 2003-2017, (ii) the *pre-crisis period* 2003-2007, (iii) the *crisis period* 2008-2011, and

[12] See Kromann et al. (2016) for a similar approach.

(iv) the *post-crisis period* 2012-2017. To account for any potential heteroskedasticity-issues and guarantee unbiased estimates, heteroskedasticity-robust t-values are reported.[13]

4.2.2. Data sources

Data for the econometric analysis stem from two key sources. The main source on industrial robots is the World Robotics Industrial Robots statistics which is available for the period 1993-2017. It is compiled by the International Federation of Robotics (IFR)[14] and contains (primary) data on robot installations by type (stock, flow), country, industry and application. The IFR measures '*multipurpose industrial robots'* based on ISO 8373: 2012 as '*an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications*' (see IFR, 2018: p29). The data is collected from nearly all industrial robot suppliers worldwide and supplemented with (secondary) data provided by several national robot associations.[15] The IFR provides data on the number of robots (stocks and flows) delivered to each industry, by country and year. It assumes a 12-year service life of a robot and calculates the operational stocks of robots as the sum of robot installations of the last 12 years.

The second key data source is the EU KLEMS 2019 release which is currently under construction and will be available for the period from 1995 to 2017 for 40 industries and 8 aggregates according to the NACE Rev. 2 industry classification. It provides information on inputs, outputs, and prices. From the EU KLEMS we take information on real value-added (at 2010 prices), employment (of persons engaged), hours worked (by persons engaged), and the breakdown of the overall capital input into ICT and non-ICT capital.[16] Non-ICT capital can further be broken down into its subcomponents and the subcomponent 'other machinery' is taken as an indicator which also includes robots, among other types of machinery.

Once both data sets are merged, a sample of 20 EU-28 Member States can be retained, comprising Austria (AT), Belgium (BE), the Czech Republic (CZ), Denmark (DK), Estonia (EE), France (FR), Finland (FI), Germany (DE), Greece (EL), Ireland (IE), Italy (IT), Lithuania (LT), the Netherlands (NL), Poland (PL), Portugal (PT), Slovakia (SK), Slovenia (SI), Spain (ES), Sweden (SE), and the United Kingdom (UK). In view of the large number of missing and zero values prior to 2002 among new EU Member States, the analysis is restricted to the period from 2002 onwards.

4.2.3. Descriptive analysis

Figure 4.2 shows overall robot density levels and growth rates for all EU-28 Member States for comparison. The average robot density levels are captured by the bars (as measured by the left-hand scale) for the periods 2002-2005 – dark shaded and in front – and 2014-2017 – light shaded bars in the back – whereas the average robot density growth rates for the entire period are represented by the red

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[13] The robot density growth rates are highly skewed. However the test on normality of error terms (Shapiro-Wilk test) cannot be rejected at conventional levels of statistical significance.

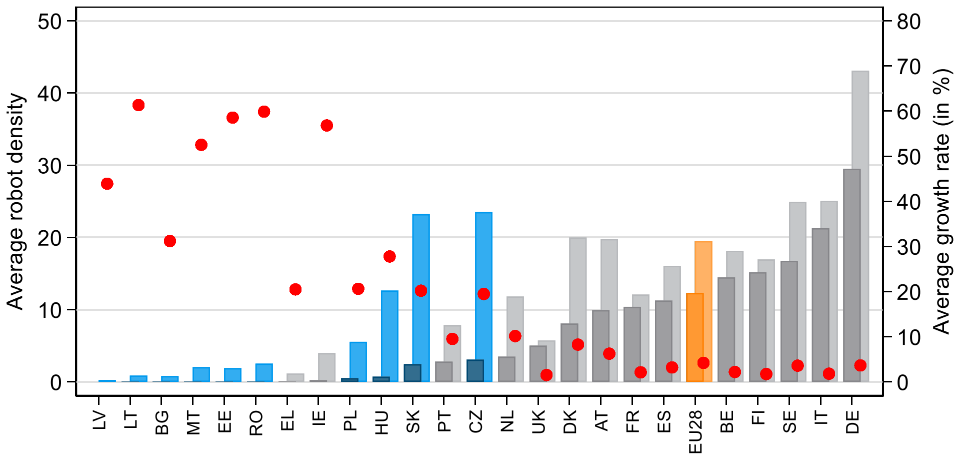
[14] See https://ifr.org/worldrobotics.

[15] Such as the national robot associations of North America (RIA), Japan (JARA) Denmark, (DIRA), Germany (VDMA, R+A), Italy (SIRI), Republic of Korea (KAR), Spain (AER), Russian Federation (RAR) and Peoples Republic of China (CRIA).

[16] ICT capital includes residential structures, total non-residential investment, transport equipment, other machinery and equipment, cultivated assets, research and development and other intellectual property products assets while non-ICT capital includes computing equipment, telecommunications equipment and computer software and databases.

dots (as measured by the right-hand scale). It shows that the variation in both robot density levels and growth rates across countries is generally high. Initially, between 2002 and 2005, robot density levels were particularly low in the majority of new EU Member States. In the case of Latvia, robot density levels were even zero. By contrast, robot density levels were highest in Germany, followed by Italy, Sweden and Finland. However, robot density levels increased a bit dramatically in the initially automation lagging countries of Central and Eastern Europe. By 2017, some Central and East European countries, particularly Slovakia, the Czech Republic, Hungary and to some extent Poland which, together with Germany and Austria constitute the Central European Manufacturing Core (Stehrer and Stöllinger, 2015), reached robot density levels on a par with those of highly automated Western European countries.

Figure 4.2 **Robot density stock (left scale) and average robot density growth rates (right scale)**



Note: Robot density is defined as the number of robots per 10,000 employees. Dark-shaded bars (front): 2002-2005; light-shaded bars (back): 2014-2017. Dots refer to the average robot density growth (right scale).

Source: World Robotics Statistics Database and EU-KLEMS Release 2019; own calculations.

4.2.4. Regression results

Table 4.1 reports the results of the estimation of equation (4.4), differentiating between the following time periods: *total* (for the average of 2003-2017), *pre-crisis* (for the average of 2003-2007), *crisis* (for the average of 2008-2011) and *post-crisis* (for the average of 2012-2017). The various columns differ in terms of the variables that are included in the estimations in addition to robot density and the total number of persons employed.

For the *total period* (columns (1)-(4)) it shows that the coefficient of the robot density indicator is generally positive and statistically significant at the 1 percent level. However, the size of the coefficient is rather small and suggests that a one percentage point increase in the growth rate of robot density is associated with an increase in labour productivity growth of only between 0.12 and 0.04 percentage points. Hence, in view of the fact that an additional growth rate of 1 percentage point on average is necessary to compensate for the future projected demographic decline, this means that the robot density growth rate needs to increase 8- to 23-fold in the near future to maintain constant real GDP growth. As concerns the remaining variables, while total capital (per person) is statistically unrelated to labour productivity, both ICT capital and non-ICT capital (per person) – the latter without the other machinery component – become significant when considered together with the robot density indicator. More specifically, both coefficients are statistically significant at the 1 percent level but, in contrast to the coefficient of the robot density indicator, relatively high. Furthermore, both coefficients are of opposite sign: The coefficient of ICT capital (per person) is positive and its size suggests that an increase in ICT capital growth of one percentage point is associated with an increase in labour productivity growth of 1.5 percentage points. By contrast, the coefficient of non-ICT capital (per person) – excluding other machinery – is negative and half the size of the coefficient of ICT capital (per person). At conventional levels of statistical significance, other machinery is statistically unrelated to labour productivity growth. As concerns the remaining variables, the coefficient of the total number of persons employed is generally positive – and only significant in one specification – which is consistent with increasing returns to scale in the production function. The CEE dummy suggests that, in the respective period, CEE EU Member States had, on average, a 1.3 percentage points higher labour productivity growth rate than their Western European peer countries.[17]

The role of robot density for labour productivity growth differs across sub-periods (see columns (5)-(16)). In the *pre-crisis period* (see columns (5) to (8)), robot density played a significant role for labour productivity growth, at the 1 and 5 percent levels of statistical significance. As concerns the other types of capital, overall capital (per person) is positively and statistically significantly related to labour productivity growth which is predominantly driven by the high and significant coefficient of the ICT capital (per person) variable which suggests that a one percentage point increase in the growth rate of ICT capital intensity is associated with a 2.5 percentage point higher labour productivity growth rate. By contrast, for the *crisis period* (see columns (9) to (12)), the coefficients of the robot density variable are insignificant (at the 1 or 5 percent level) while in for the *post-crisis period* (see columns (13) to (16)), they turn significant again. Generally, the coefficients of the robot density variable are slightly higher in the post-crisis period than the pre-crisis period which is consistent with indications that robots are becoming increasingly more important drivers of productivity growth.

4.2.5. Robustness check

In countries, where part-time work is more prevalent, the use of the total employment to calculate intensities might be misleading and result in biased results. Similarly, during the crisis period, many employers not only had to lay off workers but resorted to labour hoarding by keeping workers – despite the decline in orders – and adjusting their working hours downwards. Hence, as an additional robustness analysis, the above calculations were repeated with the total number of hours worked (by person engaged) used instead of the total number of employees.

Table 4.2 reports the results of these estimations, again differentiating between the four time periods specified above. By and large, results remain qualitatively unchanged while, as expected, some quantitative differences in coefficients emerge. For instance, for the *total period*, coefficients of the robot density indicator are slightly lower, suggesting that in order to compensate for the future projected demographic decline, the robot density growth rate needs to increase 12- to 22-fold in the near future to maintain constant real GDP growth. Furthermore, coefficients of the robot density indicator are somewhat lower in the *pre-crisis period* but slightly higher in the *post-crisis period*, pointing to the growing importance of automation for labour productivity growth in the sample of countries considered.

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[17] In another set of estimations we also accounted for the quality of workers and added the share of secondary and tertiary educated employees in the regressions. However, coefficients were generally insignificant at conventional levels of statistical significance. For the sake of brevity, results are not reported here but are available from the authors upon request.

Table 4.1 **Determinants of labour productivity growth (per employee)**

	(1) total	(2) total	(3) total	(4) total	(5) pre-crisis	(6) pre-crisis	(7) pre-crisis	(8) pre-crisis	(9) crisis	(10) crisis	(11) crisis	(12) crisis	(13) post-crisis	(14) post-crisis	(15) post-crisis	(16) post-crisis
Robot density	0.076***	0.043***	0.076***	0.124***	0.058***	0.021***	0.041**	0.045***	0.002	-0.020	-0.007	-0.002	0.042***	0.034	0.048***	0.051***
	(5.459)	(5.109)	(4.564)	(7.040)	(4.732)	(4.546)	(2.772)	(4.062)	(0.097)	(-0.722)	(-0.380)	(-0.071)	(3.352)	(1.724)	(4.078)	(4.568)
Capital per person			-0.007				0.394**				0.250				0.144	
			(-0.074)				(2.807)				(1.294)				(1.134)	
ICT capital per person				1.516***				2.529**				0.573				0.129
				(3.522)				(2.416)				(0.499)				(0.631)
Non-ICT capital per person (without Other machinery)				-0.754***				-0.049				0.118				0.279
				(-3.554)				(-0.230)				(0.241)				(1.382)
Other machinery per person				0.043				0.108				0.005				0.037
				(1.648)				(1.505)				(0.169)				(1.353)
Persons employed	0.268	0.245	0.271	1.922***	-0.895*	-0.420***	-0.822*	1.730*	-0.398*	-0.426*	-0.169	0.308	0.340	0.322	0.235	0.372
	(0.525)	(0.777)	(0.517)	(2.977)	(-2.112)	(-3.210)	(-1.979)	(1.873)	(-1.806)	(-1.918)	(-0.700)	(0.319)	(1.529)	(1.463)	(1.033)	(1.156)
CEE		1.298***				3.808***				0.952				0.177		
		(3.291)				(6.970)				(0.763)				(0.390)		
Constant	0.212	0.278	0.215	-0.493	2.436***	1.575***	1.816**	0.875	0.150	0.147	-0.195	-0.067	0.009	0.048	-0.052	-0.055
	(0.572)	(1.160)	(0.554)	(-1.415)	(3.688)	(5.391)	(2.746)	(1.249)	(0.659)	(0.620)	(-0.532)	(-0.209)	(0.047)	(0.277)	(-0.325)	(-0.265)
No of observations	20	20	20	20	19	19	19	19	20	20	20	20	20	20	20	20
R^2	0.681	0.813	0.681	0.867	0.437	0.886	0.541	0.616	0.289	0.324	0.330	0.325	0.560	0.564	0.622	0.667
Adjusted R^2	0.644	0.778	0.622	0.820	0.366	0.863	0.450	0.468	0.205	0.198	0.204	0.0843	0.508	0.482	0.551	0.547

Note: Data for Hungary are only available from 2010 onwards. Total refers to the total period 2003-2017, pre-crisis to the pre-crisis period 2003-2007, crisis to the crisis period 2008-2011, and post-crisis the post-crisis period 2012-2017. Robust t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 4.2 **Determinants of labour productivity growth (per hours worked)**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
	total	**total**	**total**	**total**	**pre-crisis**	**pre-crisis**	**pre-crisis**	**pre-crisis**	**crisis**	**crisis**	**crisis**	**crisis**	**post-crisis**	**post-crisis**	**post-crisis**	**post-crisis**
Robot density	0.072***	0.045***	0.061***	0.081***	0.050***	0.021***	0.040**	0.043***	0.016	0.014	0.013	0.013	0.051***	0.002	0.059***	0.058***
	(6.480)	(2.925)	(3.034)	(3.998)	(3.590)	(3.623)	(2.347)	(3.305)	(0.913)	(0.456)	(0.607)	(0.616)	(3.023)	(0.077)	(3.831)	(3.863)
Capital per hours worked			0.136				0.283				0.189				0.238**	
			(0.869)				(1.379)				(0.785)				(2.131)	
ICT capital per hours worked				1.308*				2.274*				-0.218				0.008
				(2.020)				(1.848)				(-0.105)				(0.026)
Non-ICT capital per hours worked (without other machiney)				-0.262				-0.317				0.323				0.344*
				(-1.333)				(-0.990)				(0.684)				(1.937)
Other machinery/hours worked				0.079				0.126				-0.019				0.063
				(1.697)				(1.680)				(-0.347)				(1.701)
Hours worked	0.042	-0.152	0.132	1.370	-0.344	-0.230	-0.454	1.960	-0.360	-0.366	-0.149	-0.215	0.133	0.107	0.036	0.083
	(0.077)	(-0.292)	(0.253)	(1.695)	(-0.622)	(-1.218)	(-0.729)	(1.748)	(-1.164)	(-1.216)	(-0.424)	(-0.104)	(0.544)	(0.463)	(0.197)	(0.205)
CEE		1.030*				3.721***				0.105				1.053		
		(1.901)				(7.894)				(0.081)				(1.722)		
Constant	0.557*	0.685**	0.403	-0.020	2.068***	1.546***	1.763**	0.759	0.267	0.265	0.000	0.100	0.338*	0.531***	0.117	0.182
	(2.027)	(2.570)	(1.210)	(-0.050)	(3.512)	(5.254)	(2.806)	(1.073)	(1.647)	(1.500)	(0.001)	(0.184)	(1.769)	(4.227)	(0.569)	(0.831)
No of observations	20	20	20	20	19	19	19	19	20	20	20	20	20	20	20	20
R^2	0.631	0.706	0.651	0.720	0.398	0.888	0.444	0.591	0.361	0.362	0.379	0.391	0.400	0.518	0.570	0.600
Adjusted R^2	0.588	0.651	0.585	0.620	0.323	0.866	0.333	0.434	0.286	0.242	0.263	0.173	0.329	0.428	0.489	0.458

Note: Data for Hungary are only available from 2010 onwards. Total refers to the total period 2003-2017, pre-crisis to the pre-crisis period 2003-2007, crisis to the crisis period 2008-2011, and post-crisis the post-crisis period 2012-2017. Robust t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

5. SUMMARY AND CONCLUSIONS

The dawning era of new technologies is often seen as having a strong negative impact on the demand for labour and therefore employment, though more recent studies indicate less alarming numbers. A number of studies point towards the substantial potential employment impacts and calculate the number of 'jobs at risk of automation'. As already cited above, the recent OECD study (OECD, 2019), for example, states that some 14% of jobs are at high risk of automation and 32% of jobs could be radically transformed (though these numbers greatly vary across countries). There are, however, several important caveats to such numbers. First, in most studies in this area, the speed and time period of job destruction (and workers' displacement) are not mentioned or are rather vague. In reality, the diffusion of new technologies may proceed at a slower pace than generally assumed and at different speeds across industries and countries. The process therefore might be considered to be less disruptive for the labour market than the sheer numbers cited above suggest. Second, while acknowledging the potentially disruptive impacts on future jobs and skill needs, and the potential for societal transformations in general, one also has to take into account the job-creating potential in producing these new technologies and the instalment of new capital. Third, in most of the literature it seems to be argued that these new technologies are (almost perfect) substitutes of labour. However, in reality it might be that they are rather substitutes for older types of capital (e.g. robots replace older production lines rather than workers). This implies that the impact on employment levels is limited. Nonetheless, one would expect at least some negative effects on labour demand from these new technologies, or stated differently, strong labour productivity growth potentials.

In this paper it is however argued that these potential employment shedding effects of the new technologies in the longer-term have to be assessed against a second pervasive trend which is particularly relevant for European countries. In some countries – particularly Central and Eastern European countries – labour shortages are likely to arise due to demographic trends characterised by a decline in the working-age population in many countries; total population will decline less rapidly due to ageing trends, however.

In such a situation of a declining labour supply it can be argued that higher labour productivity growth is needed to sustain recent trends in GDP and GDP per capita growth. As simple analysis of trend growth rates indicates that labour productivity growth would on average need to increase by about 1 percentage point to sustain real value added growth, which, on average, is equivalent to about a doubling of the labour productivity growth rates. An analysis of the contribution of ICT capital and machinery (as an indicator for the installation of new technologies like robots) to labour productivity growth according to recent trends shows that this is not (yet) strong enough to close the gap between the actual and the hypothetical labour productivity trend growth rate required to sustain GDP growth (see Atkinson, 2018, for a policy discussion focusing on ICT).

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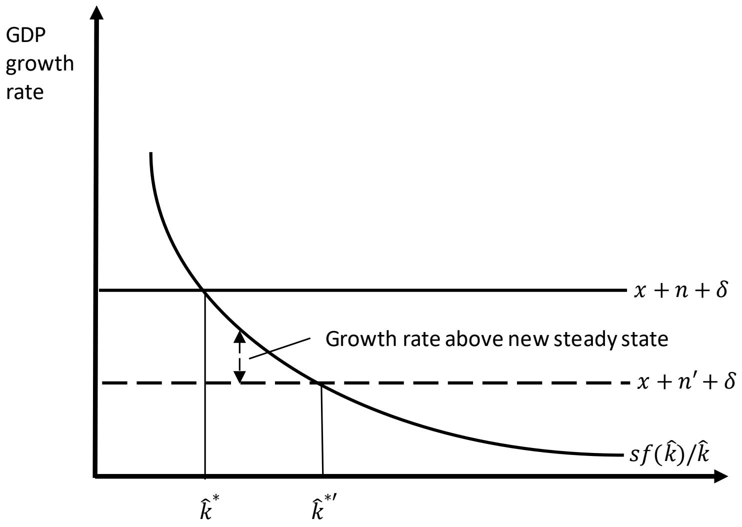
ANNEX A

Working-age population growth and technical progress in a standard Solow growth model

Theoretically, the effects of a decline in the working-age population in the Solow growth model can be seen in Figure A.1.

Figure A. 1 **The effects of a decline in employment growth in a Solow model with exogenous technical change**



Source: Barro and Sala-i-Martin (1999)[18]; own elaborations.

A decline in the growth rate of the working-age population to $n' < n$ implies that the capital per effective worker increases to $\hat{k}^{*\prime} > \hat{k}^*$; thus capital is accumulated, though the overall growth rate of the economy declines (but is still above the new steady-state growth rate in the transition phase).

Assuming that the total population declines at a slower pace than the working age population (see Figure 1 in the main text), this implies that GDP per capita growth declines. Such an effect could be counteracted by an exogenous increase in the rate of technical change x which would result in a less severe decline in overall GDP growth.

In the case that the growth rate of the working-age population (assuming constant activity rates) becomes negative, a positive long-term GDP growth rate could only be sustained with a high enough productivity growth rate. A decline in n – that is lower (working-age) population growth due to demographic change - would imply a lower GDP growth rate and a higher growth rate of capital per effective worker in the new steady-state. However, the lower (steady-state) growth rate would then imply that GDP per capita (total population) growth would go down (if population growth is less negative than growth of the working-age population). Hence, to maintain the initial and higher GDP growth rate, a higher rate of (labour augmenting) technical change is needed.[19] Though not fully

[18] Barro, R.J and X. Sala-i-Martin (1995), Economic Growth, McGraw-Hill.

[19] Alternatively, the savings rate of the economy could increase to maintain the initial level of growth.

consistent with theory, a part of the increase in the rate of (labour augmenting) technical change might stem from the adoption and implementation of new technologies (and related capital).

Since productivity growth is partly driven in capital formation, this paper investigates to which extent capital accumulation (which embodies new technologies and results in labour augmenting technical change, e.g. in the form of robots) shifts up the dashed line (if at all). Additionally, an increase in the depreciation rate δ (which becomes larger as the new technologies like ICT have higher depreciation rates and gain more weight) would shift up the dashed line.

Generalisations of outlined model

This expression can further be discussed by assuming that labour productivity growth depends – amongst other factors – on the growth rate of the (working-age) population (e.g. faster growing younger populations tend to have higher productivity growth rates) and the growth rate of real GDP (i.e. by arguing a Kaldor-Verdoorn effect). As a simple exposition assume that $\varphi = \varphi_0 + \lambda_n n + \lambda_y y$. Inserting above and rearranging yields

$$y = \frac{1 + \lambda_n}{1 - \lambda_y} n + \frac{1}{1 - \lambda_y} \varphi_0$$

Assuming a positive relation between real GDP and productivity growth, $\lambda_y > 0$, real GDP growth is positively affected given n and φ_0. Assuming a positive relation between productivity and population growth this implies that a higher growth of population leads to an even higher real GDP growth rate (due to higher labour productivity growth). However, this also implies that a negative population growth impacts over-proportionally negatively on real GDP growth.

Inserting the more general equation for value added growth into $e = y - \varphi$ yields

$$e = y_t - \varphi_t = y - \varphi_0 - \lambda_n n - \lambda_y y = (1 - \lambda_y) y - \varphi_0 - \lambda_n n$$

Inserting the growth rate of real value added growth gives

$$e = (1 - \lambda_y) \left[\frac{1 + \lambda_n}{1 - \lambda_y} n + \frac{1}{1 - \lambda_y} \varphi_0 \right] - \varphi_0 - \lambda_n n$$

which results in $e = [(1 + \lambda_n) n] - \lambda_n n$ and thus $e = n$. This means, in the long-term, that employment growth has to be in line with the growth of working-age population (if no changes in the activity rates are considered and labour productivity is related to working-age population growth and GDP growth).

Further, one has to consider the impact of a declining work force on GDP per capita growth. The recent trends (and population forecasts) suggest that the working-age population is declining more rapidly than the total population (due to ageing).

$$y - n_{Pop} = \frac{1 + \lambda_n}{1 - \lambda_y} n + \frac{1}{1 - \lambda_y} \varphi_0 - n_{Pop}$$

This simple expression shows that GDP per capita growth also becomes lower in the case of a decline in the working-age population. Again, if the demographic trends are exogenous, this might be counteracted by a higher productivity growth rate φ_0.

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