The contribution of robots to productivity growth in 30 OECD countries over 1975–2019

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A B S T R A C T

Using a new and original database, our paper contributes to the growth accounting literature by singling out the contribution of robots through two channels: capital deepening and TFP. The contribution of robots to productivity growth through capital deepening and TFP appears to have been significant in Germany and Japan in the sub-period 1975–1995 and in several Eastern European countries in 2005–2019. However, robotization does not appear to be the source of a significant revival in productivity.

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JEL classification: O31 O33 O47

1. Introduction

While ICTs, robots and new productivity-enhancing digital technologies continue to spread at a sustained rate, productivity growth has slowed down in all advanced economies in the last few decades (Bergeaud et al., 2018; Gordon and Sayed, 2020). The aim of this study is to contribute to analyse such "productivity paradox" by singling out the contribution of robots, which are bundled in the SNA non-ICT capital stock, to productivity growth within a growth accounting approach. Robots can now perform a wide range of tasks, with very little or no human intervention. Unlike ICTs, they are able of flexible movements in three dimensions, which were previously exclusive to human beings.

A growing literature shows the contribution of robots to productivity growth, e.g.: Acemoglu et al. (2020) based on French firm-level data or Graetz and Michaels (2015, 2018) on industry-level data for several countries. While the impact of robot adoption on productivity appears large at the firm level, these analyses suggest that it is small and far below that of ICTs at the country level. Using an original country-level database, this paper extends previous analyses to a longer period (1975–2019) and a larger set of countries (30 OECD countries). Our results show that in most countries, including the US, the average robots' contribution to productivity growth in 1975–2019 did not exceed 0.2 pp. a year. The contribution was the largest in Germany in the sub-period 1996–2005 (0.7 pp.) and in Japan in 1976–1995 (0.87 pp.) but decreased in both countries afterwards. Robots' contribution was also significant in the Eastern European countries from the 2000s, due to the outsourcing of manufacturing activities, particularly in the automotive sector, from Western European countries, for instance Germany, to these countries. Overall, these results suggest that robotization has not been the source of a significant revival in productivity.

2. Data and growth accounting methodology[1]

To carry on our growth accounting evaluation, we collected data on GDP at constant price 2015, hours worked and robots in 30 countries — plus the Eurozone[2] - over 1951–2019. GDP data are drawn from several databases: BEA for the USA, Eurostat,

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[1] For more details concerning the construction of the database, see Cette et al. (2020).

[2] Euro Area has been reconstituted, aggregating Germany, France, Italy, Spain, The Netherlands, Belgium, Austria, Finland, Greece, Ireland, and Portugal, these 11 countries representing together, in 2018, 97% of the Euro Area GDP.

OECD, Penn World Table 1, and the UN. GDP deflators are from the BEA for USA, INSEE for France, Eurostat, OECD and Penn World Table 1 for all other countries. Deflators have been extrapolated from 1950 to 1989 for the Czech Republic, Estonia, Lithuania, Latvia, Slovakia, Slovenia and from 1950 to 1969 for Hungary.

The number of hours worked is the average annual working time per worker multiplied by the employment. The sources of these two indicators are *LongTermProductivity database* (LTP here after), OECD, TED (Total Economy Database). The LTP database contains data from 1950 for the following countries: Australia, Austria, Belgium, Canada, Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, Israel, Italia, Japan, Mexico, Netherlands, Norway, New-Zealand, Portugal, Sweden and USA. For the other countries, we use OECD and TED. The working time per worker is extrapolated for Czech Republic, Estonia, Hungary, Israel, Lithuania, Luxembourg, Latvia, Slovakia and Slovenia from 1950 to 1994 at the latest.

Data on robots are drawn from the World Robotics Industrial Robots statistics compiled by the International Federation of Robots (IFR), covering installations and the operational stocks of robots from 1983 to 2019, with partially available data. We consider the industrial robots, corresponding to the definition of the International Organization for Standardization (ISO 8373:2012): an "*automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes*".

IFR collects data on robot installations by country, industry and application from nearly all industrial robot suppliers worldwide. It complements this information with data from several national robot associations, including Korean Association of Robot Industry (KAR), the Japanese Robot Association (JARA), the Robotic Industries Association (RIA) providing data on North America and the Chinese Robot Industry Alliance (CRIA). Prior 2004, country reports relied exclusively on data of national robot associations.

The operational stock of robots measures the number of robots currently deployed. JARA calculates and provides this figure for Japan. For all other countries, IFR calculates the operational stock assuming an average service life of 12 years with an immediate withdrawal from service afterwards (see IFR, 2001 for a discussion about the length of the service life).

To complete the IFR database and extend the series back to 1960, we estimated the stock of operational robots based on an OLS regression on the stock of each of the three ICT capital products (hardware, software and telecommunication), with fixed effects for countries and a common trend. This method has been preferred after robustness tests made with other regressions.[3]

To carry out our growth accounting evaluation, we use the estimates by Graetz and Michaels (2015) based on a panel of 14 developed countries, which seem consistent (as far as the comparison is possible) to the ones of Acemoglu et al. (2020) estimated on a panel of French firms. The relevant set of estimates by Graetz and Michaels (2015) are shown in Table 1. Line (1) shows the estimated elasticity of labour productivity *to the number of robots per million hours worked* (0.144). (2) shows the estimated elasticity of labour productivity to *percentile changes in the number of robots per million hours worked* (0.873). (3) shows the estimated elasticity of TFP to *percentile changes in the number of robots per million hours worked* (0.663). As the three elasticities have been estimated based on the same specification and the same sample, (2) and (3) together imply that 76% (i.e.: 0.663/0.873) of the estimated contribution of robots to labour productivity occurs via TFP while the remaining 24% is accounted for by capital deepening. Applying this decomposition to the elasticity in (1), we obtain our coefficients to estimate the contribution of the *number of robots per million hours worked* to labour productivity via TFP (0.76*0.144 = 0.1044) and via capital deepening (0.24*0.144 = 0.0396). Based on those estimates, we are able to single out the contribution of robots to labour productivity growth through the two channels: capital deepening and TFP. Robots are part of non-ICT capital, their ICT components being intermediate consumption of robot producers (see Cette et al., 2019).

Table 1
Estimated elasticities of labour productivity to robots.
Source: Based on Graetz and Michaels (2015), Tables A7 (2), A6 (2) and 6 (2).

		Δln(VA/H)	Δln(TFP)
(1)	Δ (R/H)	0.144	
(2)	Δ percentile of (R/H)/100	0.873	
(3)	Δ percentile of (R/H)/100		0.663

Note: R stands for number of robots, H stands for million hours worked, VA per value added and TFP for Total Factor Productivity. All estimates are instrumental variables (IV).

The above elasticity being estimated by Graetz and Michaels (2015) on the set of sectors using robots, we have weighted its effect by the share of those sectors in the total value added in each country.[4]

A limitation of this evaluation is that it assumes, like Graetz and Michaels (2015, 2018), that robot contribution to productivity growth depends only on the average number of robots per hour worked, and that there is no change in the average robot quality. Implicitly, it means that the price of robots relative to the output price would have been on average stable over the evaluation period. For this reason, our evaluation of the impact of robotization on productivity growth should probably be considered as a lower estimate.

3. Robot diffusion and contribution to labour productivity growth[5]

Graetz and Michaels (2018) estimate that the price of industrial robots in six major developed economies (France, Germany, Italy, Sweden, the United Kingdom and the United States) in 1990–2005 fell by about 50% in nominal terms and 80% when adjusted for quality. Such a decrease has fuelled rapid diffusion in robots in a number of economies.

The diffusion of robots started in the early 70s, first in Japan, followed by Germany (Fig. 1). In other countries, robot diffusion started to pick about a decade later. Japan had the highest penetration of robots in the sample until 2011, when Germany took the lead. In Japan, the number of robots per million hours worked decreased in 1998–2003 due to the crisis of the IT sector, fluctuated in 2004–2008 and decreased further in 2009–2017, following the delocalization of activities in the automobile, electrical and electronic industries.

While penetration has been increasing steadily in other countries, the number of robots per millions of hours worked remains lower than in Germany and Japan (Fig. 2). Among them, Slovenia, the Czech Republic, Italy, Slovakia and Sweden show the highest values (above 1.5 robots per millions of hours worked).

Robots tend to be concentrated in few manufacturing sectors. Transport equipment account for about 45% of the world stock of robots, Electronic, electrical and optical equipment for 30%, rubber and plastic for 8% and Metal products for between 6%.

[3] Detailed results of these econometric estimates are available upon request from the authors.

[4] Robot-using industries include ISIC Rev.4 01–03, 05–09, 10–32, 35–39, 41–43 and 72.

[5] Detailed results concerning each of the 30 countries of our dataset are available upon request from the authors.

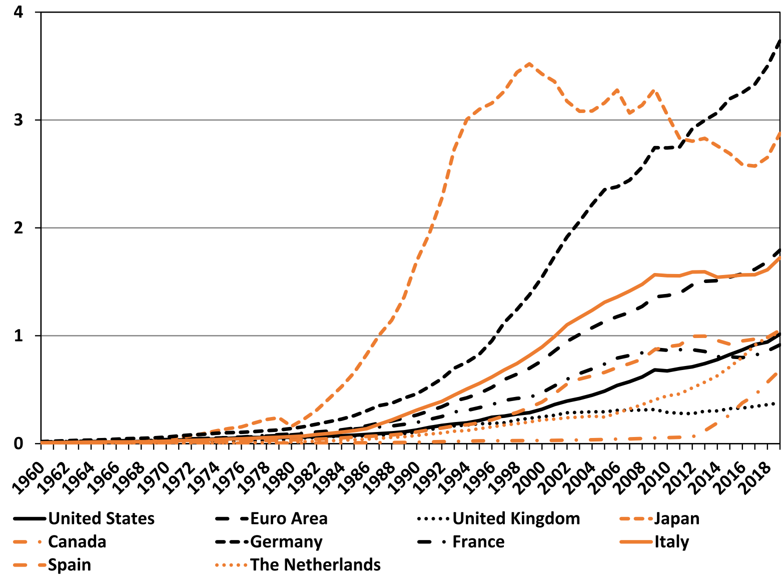

Fig. 1. Robot diffusion, 1960–2019 Number of robots per million hours worked.
Source: Authors' calculations.

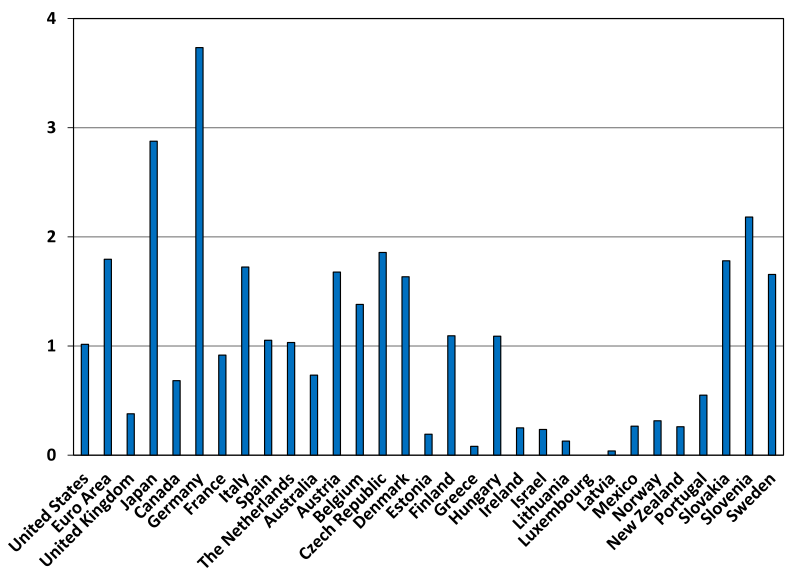

Fig. 2. Robot diffusion, 2019 Number of robots per million hours worked.
Source: Authors' calculations.

Therefore, the observed patterns of diffusion also reflect country-specific specializations.

While the effects of robots are a matter of vivid debate among economists (for instance Brynjolfsson and McAfee, 2014; Autor, 2015; Presidente, 2019; Acemoglu and Restrepo, 2020), only a few empirical studies have looked at their impact on productivity. Among the few exceptions, Graetz and Michaels (2018) found that increased robot use contributed approximately 0.36 percentage points to annual labour productivity growth in 17 countries from 1993 to 2007. Our findings below extend their results to a wider set of countries (30) over a longer time period (since the mid-1970 and until 2019).

As robots' diffusion starts to pick up in the mid-1970s, we look at their contribution over three periods: 1975–1995 (from the first oil shock to the starting point of the ICT diffusion); 1995–2005 (the peak of the ICT diffusion); and 2005–2019 (the end of the period including the Great Recession) (Fig. 3).

Robots' average yearly contribution to productivity growth appears the largest in Germany, particularly in the period 1996–2005 (0.7 percentage points). In Japan, robots' contribution reached a peak in 1976–95 (0.87 pp.), dropped in the next period (0.03 pp.) and become negative in 2006–19 (−0.09 pp.) following the decrease in the stock of robots commented above. In the period 2006–19, following the outsourcing of manufacturing activities, particularly in the automobile sector, to these countries, the contributions of robots increased significantly in Slovakia (0.75 pp.), the Czech Republic and Slovenia (both 0.74 pp.) and, to a lesser extent Hungary (0.41 pp.) and Austria (0.36 pp.). Robots' contribution was also sizeable in Italy (0.36 pp.) and Finland (0.32 pp.) in 1996–2005 as well as in Denmark in 2006–19 (0.3 pp.). In most of the remaining countries, including the US, robots' contribution to productivity growth did not exceed 0.2 pp. a year on average.

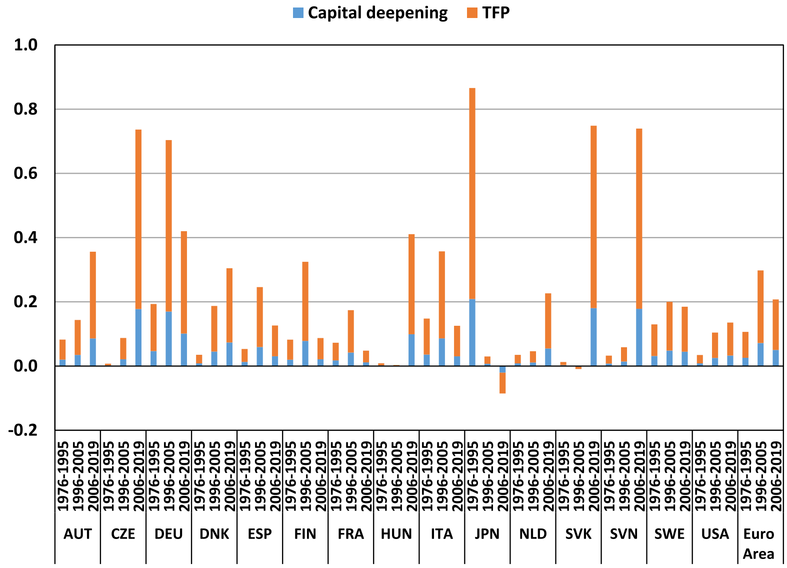

Fig. 3. Robots contribution to labour productivity growth In percentage points (pp.).
Source: Authors' calculations.

4. Conclusion

Using an original database, this paper estimates the contribution of robots to productivity growth through two channels, capital deepening and TFP, in 30 OECD countries over the period 1975–2019. Our results show that in most countries, including the US, the average robots' contribution to productivity growth in 1975–2019 did not exceed 0.2 pp. a year. This contribution was the largest in Germany in the sub-period 1996–2005 (0.7 pp.) and in Japan in 1976–1995 (0.87 pp.) but decreased in both countries afterwards. Robots' contribution was also significant in the Eastern European countries from the 2000s, due to the outsourcing of manufacturing activities, particularly in the automotive sector, from Western European countries, for instance Germany, to these countries. Overall, these results suggest that robotization has not been the source of a significant revival in productivity.

References

Acemoglu, Daron, Lelarge, Claire, Restrepo, Pascual, 2020. Competing with robots: Firm-level evidence from France. Amer. Econom. Rev. Pap. Proc. 110, 383–388.

Acemoglu, Daron, Restrepo, Pascual, 2020. Robots and jobs: Evidence from US labor markets. J. Polit. Economy 128 (6), 2188–2244.

Autor, David, 2015. Why are there still so many jobs? The history and future of workplace automation. J. Econ. Perspect. 29, 3–30, 3.

Bergeaud, Antonin, Cette, Gilbert, Lecat, Rémy, 2018. The role of production factor quality and technology diffusion in twentieth-century productivity growth. Cliometrica 12 (1), 61–97.

Brynjolfsson, Erik, McAfee, Andrew, 2014. The Second Machine Age – Work, Progress, and Prosperity in a Time of Brilliant Technologies. W. W. Norton & Company.

Cette, Gilbert, Devillard, Aurélien, Spiezia, Vincenzo, 2020. Growth factors in developed countries: A 1960–2019 growth accounting decomposition, Banque de France, Working Paper, n° 783, October.

Cette, Gilbert, Lopez, Jimmy, Presidente, Giorgio, Spiezia, Vincenzo, 2019. Measuring 'indirect' investment in ICT in OECD countries. Econom. Innov. New Technol. 28 (4), 348–364.

Gordon, Robert J., Sayed, Hassan, 2020. Transatlantic Technologies: the Role of ICT in the Evolution of U.S. and European Productivity Growth, CEPR Discussion Paper No. DP15011, Vol. 38. https://ssrn.com/abstract=3650126. Also available in International Productivity Monitor, Spring, pp. 50-80.

Graetz, Georg, Michaels, Guy, 2015. Robots at work, CEPR, Discussion Paper No. 10477, March.

Graetz, Georg, Michaels, Guy, 2018. Robots at work. Rev. Econ. Stat. 100 (5), 753–768.

Presidente, Giorgi, 2019. Determinants and impact of automation: An analysis of robots' adoption in OECD countries, OECD Digital Economy Papers, No. 277, OECD Publishing, Paris. http://dx.doi.org/10.1787/ef425cb0-en.