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August 2017

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Working Paper 06/2017

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Abstract

We analyze the effects of automation on the wages of high-skilled and low-skilled workers and thereby on the evolution of wage inequality. Our model explains the simultaneous presence of i) increasing per capita income, ii) declining real wages of low-skilled workers, and iii) an increasing skill-premium. These developments are consistent with the experience in the United States over the past decades.

JEL classification: O11, O41, I24.

Keywords: automation, declining wages of low-skilled workers, wage inequality, skill premium, long-run growth.

1 Introduction

Despite sustained economic growth in the United States throughout the 20th century, real wages of low-skilled workers have been declining since the 1970s (Acemoglu and Autor, 2012; Autor, 2014). Together with the strong rise in the real wages of workers with a bachelor's degree or higher, this has led to a substantial increase in the skill-premium. A widely accepted and convincing explanation for the rise in the skill premium is skill-biased technical change that disproportionately raised the productivity of high-skilled workers (cf. Acemoglu, 2002). Other developments – such as international trade and outsourcing – have complemented skill-biased technological change in its effect on the wage differential (Autor et al., 2016).

There is another aspect that might have played an important role in this context, namely automation (Acemoglu and Restrepo, 2015; Hémous and Olsen, 2016). We therefore incorporate automation and heterogeneous skills into an otherwise standard and very simple model of capital accumulation. Consistent with the stylized facts up to now, we assume that low-skilled labor is easier to automate than high-skilled labor. The resulting framework is capable of generating automation-driven long-run growth even in the absence of technological progress and it explains the rise in the skill premium. In contrast to the model of skill-biased technological change, our framework is able to explain the reduction in the real wages of low-skilled workers that we have observed over the past decades in the United States.

2 The model

Consider an economy that is populated by households who invest a fraction s of their income.[1] Time t evolves continuously and the population grows at rate n. There are four production factors: low-skilled workers denoted by L_u, high-skilled workers denoted by L_s, traditional physical capital in the form of machines, assembly lines, and production halls denoted by K, and automation capital in the form of industrial robots and 3D printers, denoted by P. Automation capital is a perfect substitute for low-skilled workers but an imperfect substitute for high-skilled workers. Suppressing time arguments whenever this does not impair the clarity of exposition, the representative firm produces output Y according to the production function

$$Y = \left[(1-\beta)L_s^\gamma + \beta\,(P + L_u)^\gamma\right]^{\frac{1-\alpha}{\gamma}} K^\alpha, \tag{1}$$

[1]We abstract from endogenous investment decisions that would mainly lead to a much more complicated exposition, particularly during the transition phase. See Steigum (2011) for an analysis of the growth effects of automation in a model with endogenous investments but without heterogeneous labor.

where $\beta \in (0,1)$ is the production weight of low-skilled workers, $\gamma \in [0,1]$ measures the substitutability between both types of workers (they are perfect substitutes for $\gamma = 1$ and complements for $\gamma = 0$), and α is the elasticity of output with respect to traditional physical capital. Denoting the fraction of investment diverted to the accumulation of traditional capital by s_K and the rate of depreciation by δ, the laws of motion of both types of capital are given as in Prettner (2017):

$$\dot{K} = s_K s Y - \delta K, \tag{2}$$

$$\dot{P} = (1 - s_K) s Y - \delta P. \tag{3}$$

Assuming different rates of depreciation for both types of capital would not change the main qualitative results.

For simplicity, we abstract from endogenous education that would allow individuals to switch from being low-skilled to being high-skilled. Considering education decisions would primarily affect the transitional dynamics as in Prettner and Strulik (2017). Denoting the size of the workforce by $L = L_u + L_s$, defining the shares of high-skilled and low-skilled workers by $l_s = L_s/(L_s + L_u)$ and $l_u = L_u/(L_s + L_u)$, and referring to per capita counterparts of aggregate variables with lowercase letters, yields per capita GDP as

$$y = \left[(1-\beta) l_s^\gamma + \beta\,(p + l_u)^\gamma\right]^{\frac{1-\alpha}{\gamma}} k^\alpha. \tag{4}$$

It is straightforward to show that the per capita dynamics of traditional capital and of automation capital are given by

$$\dot{k} = s_K s \cdot y - (\delta + n) k, \tag{5}$$

$$\dot{p} = (1 - s_K) s \cdot y - (\delta + n) p. \tag{6}$$

As a consequence, the per capita growth rates of traditional capital, g_k, and of automation capital, g_p, are

$$g_k = s_K s \left[(1-\beta) l_s^\gamma + \beta (p + l_u)^\gamma\right]^{\frac{1-\alpha}{\gamma}} k^{\alpha - 1} - (\delta + n), \tag{7}$$

$$g_p = (1 - s_K) s \left[(1-\beta) l_s^\gamma + \beta (p + l_u)^\gamma\right]^{\frac{1-\alpha}{\gamma}} k^\alpha p^{-1} - (\delta + n). \tag{8}$$

These two equations fully describe the growth process of both accumulable production factors in our setting.

3 Results

It can be shown that a steady state exists in which the per capita stocks of both types of capital are positive but do not grow such that the economy stagnates (as in Solow, 1956). However, there is the more interesting case of a long-run balanced growth path along which the economy grows at a constant rate, despite the absence of technological progress. To calculate this growth rate, we use the definition of a balanced growth path according to which the per capita growth rates of both types of capital are constant, i.e., $\dot{g}_k = \dot{g}_p = 0$. Recalling Equations (7) and (8), this yields the result that the growth rates of k and p have to be equal along the balanced growth path such that $\dot{k}/k = \dot{p}/p$. For $\lim_{p\to\infty}$ and constant l_s and l_u, we can equate (7) and (8) and use the approximation $(1-\beta)l_s^\gamma + \beta(p+l_u)^\gamma \approx \beta(p+l_u)^\gamma \approx \beta p^\gamma$ to derive the common asymptotic growth rate of traditional physical capital and automation capital as

$$g = \beta^{\frac{1-\alpha}{\gamma}} \cdot s \cdot s_K^\alpha (1-s_K)^{1-\alpha} - (\delta + n). \tag{9}$$

Equation (4) implies that per capita output also grows at rate g because

$$\begin{aligned} ln(y) &= \frac{1}{\gamma}(1-\alpha) \cdot ln\left[(1-\beta)l_s^\gamma + \beta\left(p+l_u\right)^\gamma\right] + \alpha \cdot ln(k) \\ &\approx \frac{1}{\gamma}(1-\alpha) \cdot ln\left(\beta p^\gamma\right) + \alpha \cdot ln(k) \\ \Rightarrow \frac{\mathrm{d}ln(y)}{\mathrm{d}t} &= g_y = (1-\alpha)g_p + \alpha g_k = g. \end{aligned}$$

At this stage we can state our first central result.

Proposition 1. *In our framework there exists a balanced growth path with positive long-run economic growth at rate g. This growth rate increases with the savings rate (s) and with the substitutability between low-skilled and high-skilled workers (γ), whereas it decreases with the rates of population growth (n) and depreciation (δ).*

Proof. The proposition follows immediately from inspecting Equation (9) and noting that $\beta < 1$ such that an increase in γ raises the the first term in this expression. □

The results in Proposition 1 generalize the results of Prettner (2017) to a model with two different types of skills, where low-skilled labor is easier to substitute by automation than high skilled labor. The intuition for the finding of perpetual growth in the absence of technological progress is that automation turns labor into an accumulable production factor. The easier it is to substitute between the two types of workers, the stronger the effect becomes.

At that stage, we can state our second central result.

Proposition 2. *In our framework, the accumulation of automation capital leads to* *i) decreasing wages of low-skilled workers,*

ii) decreasing wages of high-skilled workers, if low-skilled workers and high-skilled workers are easy to substitute,

iii) an increasing skill premium.

Proof. Assuming perfect competition, the wages of high-skilled workers (w_s) and the wages of low-skilled workers (w_u) are given by

$$w_s = (1-\alpha)\frac{Y}{L_s^{1-\gamma}}\frac{1-\beta}{(1-\beta)L_s^{\gamma}+\beta\left(P+L_u\right)^{\gamma}}, \tag{10}$$

$$w_u = (1-\alpha)\frac{Y}{(P+L_u)^{1-\gamma}}\frac{\beta}{(1-\beta)L_s^{\gamma}+\beta\left(P+L_u\right)^{\gamma}}. \tag{11}$$

The effect of an increase in the stock of automation capital on the wages of low-skilled workers is:

$$\frac{\partial w_u}{\partial P} = \frac{(1-\alpha)\beta Y}{(P+L_u)^{2-\gamma}}\frac{\{(1-\alpha-\gamma)\beta\left(P+L_u\right)^{\gamma}-(1-\gamma)\left[(1-\beta)L_s^{\gamma}+\beta\left(P+L_u\right)^{\gamma}\right]\}}{\left[(1-\beta)L_s^{\gamma}+\beta\left(P+L_u\right)^{\gamma}\right]^2}. \tag{12}$$

Since $(1-\alpha-\gamma)\beta\left(P+L_u\right)^{\gamma} < (1-\gamma)\beta\left(P+L_u\right)^{\gamma}$, the numerator of the second term is always negative and so is the whole derivative. Consequently, the accumulation of automation capital reduces the wages of low-skilled workers. This proves part i) of the proposition.

The effect of an increase in the stock of automation capital on the wages of high-skilled workers is:

$$\frac{\partial w_s}{\partial P} = (1-\alpha)Y\frac{(1-\beta)\beta L_s^{\gamma}}{L_s(P+L_u)^{1-\gamma}}\frac{1-\alpha-\gamma}{\left[(1-\beta)L_s^{\gamma}+\beta\left(P+L_u\right)^{\gamma}\right]^2} = \begin{cases} \geq 0 & \text{for} \quad 1-\alpha \geq \gamma, \\ < 0 & \text{for} \quad 1-\alpha < \gamma. \end{cases} \tag{13}$$

The influence of automation on the wages of high-skilled workers is therefore ambiguous and depends on the substitutability between both types of labor. If γ is high and substitution is easy, an increase in the use of robots even reduces the wages of high-skilled workers. This proves part ii) of the proposition.

The skill-premium is defined as the ratio of the wages of high-skilled workers to the wages of low-skilled workers:

$$\frac{w_s}{w_u} = \frac{1-\beta}{\beta}\left(\frac{P+L_u}{L_s}\right)^{1-\gamma}. \tag{14}$$

As long as $\gamma < 1$, which implies imperfect substitution between the two types of skills as required in the proposition, an increase in the stock of automation capital, P, raises the skill premium. This proves part iii) of the proposition. $\square$

The intuition for this result is that competition by automation leads to decreasing wages of low-skilled workers. Together with the fact that the wages of high-skilled workers increase – or at least decrease by less than the wages of high-skilled workers – this implies a rising skill-premium. Altogether, our results are in line with the data for the United States since the 1970s as presented in Acemoglu and Autor (2012) and Autor (2014). Consequently, automation might be an important aspect for explaining the evolution of wage inequality.

4 Conclusions

We analyze the effects of automation in a model with low-skilled and high-skilled workers and show that i) there is perpetual growth despite the absence of technological progress, ii) automation decreases the real wages of low-skilled workers, iii) automation raises the skill premium. All three results are consistent with the data for the United States over the past decades and help to explain why the less-well educated did not benefit despite overall economic growth.

Acknowledgments

We would like to thank Anna Dugan for valuable comments and suggestions.

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ECON WPS

Vienna University of Technology Working Papers
in Economic Theory and Policy

ISSN 2219-8849 (online)
http://www.econ.tuwien.ac.at/wps/

August 2017

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