Trade unions and automation: A theoretical approach

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Abstract: Automation has had a profound impact on the economy, which has led to it being a widely discussed topic not only in economics over the past few years. However, the pertinent literature on the possible interplay between trade unions and automation is still relatively meager. Therefore, this article strives to contribute to the body of literature by analyzing theoretical effects of automation on the decision-making of trade unions. For this purpose, a model of the firm and a trade union akin to van der Ploeg (1987) is constructed. The firm employs capital, labor, and automatable capital, which is assumed to be a perfect substitute for labor. The trade union maximizes its utility by choosing an optimal amount of labor employed by the firm with the wage being determined by the demand for labor. By means of optimal control, we show that the employment of automatable capital can have an adverse effect on the optimal amount of labor.

Keywords: trade unions, automation, optimal control
JEL Classification: C61, J51, O33

1 Introduction

The impact of technological changes on the economy has long been a pertinent area of economic research. In particular, the implications of automation for the labor market have been extensively studied in papers such as Acemoglu (2002), Acemoglu and Restrepo (2018, 2019, 2020, 2021, 2022), Autor and Dorn (2013), Frey and Osborne (2017), Prettner and Strulik (2020). The articles study topics such as the impact of automation on the labor share and wage inequality, substitutability of various tasks by automatable capital and robots, the interaction between education, automation and labor market, all of which are of paramount importance. However, the body of literature on the possible interplay between trade unions and automation is relatively meager. A line of the research tries to explain the how technological change may cause a drop in the unionization rate. For instance, Acemoglu et al. (2001) argue that skill-biased technological change may account for the declining unionization rates. This result is supported by Acikgoz and Kaymak (2004) and Dinlersoz and Greenwood (2016).

It is essential to study the impact of automation on the trade union decision making as it can have a profound effect on the wages as well as the unemployment. Therefore, this article strives to contribute to the body of literature by analyzing theoretical effects of automation on the decision-making of trade unions in the framework of a growth model. For this purpose, a model of the firm and a trade union akin to van der Ploeg (1987) is constructed. Although the model analyzes a single firm only, it could be extended to the whole economy (albeit with more complex analysis) as it already contains the main features of a whole-economy model. The model is introduced in the next section. The results thereof are discussed, conclusions are drawn and prospects for future research are provided in the last section of the article.

2 The Model

In this section, we build the model for our analysis. We begin by considering the firm first and then move on to the decision-making of the trade union.

2.1 The Firm

Let us begin our analysis by first considering the firm. Its production function is of the following form:

$$Y = f(x, y) = f(K, L + mP) \tag{1}$$

where:
Y product
K capital
L labor
P automated capital
m parameter; either 0 or 1[1]

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[1] Should the parameter attain real values between 0 and 1, a certain level of imperfect substitutability would be introduced in the model. We do not pursue it here, however, since a much standard form of imperfect substitutability would be by raising the automatable capital

Function f is assumed to be as smooth as necessary with the following restrictions on its derivatives:

$$\frac{\partial f}{\partial x} > 0, \frac{\partial f}{\partial y} > 0, \frac{\partial^2 f}{\partial x^2} < 0, \frac{\partial^2 f}{\partial y^2} < 0, \frac{\partial^2 f}{\partial x \partial y} = \frac{\partial^2 f}{\partial y \partial x} > 0 \tag{2}$$

Economically, these conditions imply that the marginal products are positive, but decreasing. The last inequality signifies that an increase in either labor or automated capital increases the marginal product of capital and, because of the assumed smoothness of the function, the order of the cross derivatives can be changed so that an increase in capital increases the marginal product of labor or automated capital. We also adhere to the convention of omitting the function arguments in derivatives.

Automated capital P is assumed to be a perfect substitute for labor L. The parameter m denotes the possibility of substituting labor with automated capital. If it attains the value 0, no such substitution is possible. If its value is 1, then labor can be substituted with automated capital. Both capital and automated capital are assumed to change in time according to the following ordinary differential equations (henceforth ODEs):

$$\frac{dK}{dt} = i_K - \delta K \tag{3}$$

$$\frac{dP}{dt} = i_P - \delta P \tag{4}$$

where:
t time
δ depreciation rate; a real number between 0 and 1
i_K capital investment
i_P automated capital investment

For the sake of clarity, the depreciation rate is assumed the same for both capital and automated capital. The firm chooses the investment goods as well as labor so as to maximize its discounted profit functional[2]:

$$\max_{L, i_K, i_P} \int_0^\infty e^{-\rho t}\left(f(K, L + mP) - wL - p_K i_K - p_P i_P - {i_K}^2 - {i_P}^2\right) dt \tag{5}$$

where:
ρ discount rate; a positive real number
w wage; a positive real number
p_K capital investment price; a positive real number
p_P automated capital investment price; a positive real number

The last quadratic terms in the functional denote installation costs of investment goods and, for the sake of simplicity, are chosen to be quadratic with no parameters. Furthermore, the product is a numéraire and, hence, its price is set to 1. Optimal amount of labor can be found to be:

$$\frac{\partial f}{\partial y} = w \tag{6}$$

Equation (6) plays a vital role in our analysis as it links wages and labor. This enables us to conduct the analysis of trade union optimization the way it is done later in the text. Determining an optimal level of investment goods is a bit more complex and needs to be done by means of optimal control. The corresponding current value Hamiltonian of the problem is:

$$\mathcal{H} = f(K, L + mP) - wL - p_K i_K - p_P i_P - {i_K}^2 - {i_P}^2 + \lambda_K(i_K - \delta K) + \lambda_P(i_P - \delta P) \tag{7}$$

The parameters λ (and later μ) have a similar interpretation to the Lagrange multiplier with the difference that they are not mere constants but functions of time. The reader is referred to the relevant literature on dynamic optimization (see Footnote 2) for further information. The first-order conditions (henceforth FOCs) yield:

$$i_K = \frac{\lambda_K - p_K}{2} \tag{8}$$

to a power. Another possibility for further research would be to assume that the parameter either changes in time or is dependent on the relative amount of automatable capital employed with respect to the amount of labor employed.

[2] Dynamic optimization in economics can be found in Dixit (1990), Kamien and Schwartz (1991), Chiang (1992) or Acemoglu (2009).

$$i_P = \frac{\lambda_P - p_P}{2} \tag{9}$$

$$\frac{d\lambda_K}{dt} = (\rho + \delta)\lambda_K - \frac{\partial f}{\partial x} \tag{10}$$

$$\frac{d\lambda_P}{dt} = (\rho + \delta)\lambda_P - m\frac{\partial f}{\partial y} \tag{11}$$

2.2 The Trade Union

Let us now turn our attention to the trade union. It is assumed to maximize the discounted wage bill functional:

$$\max_L \int_0^\infty e^{-\rho t} wL dt \tag{12}$$

The trade union chooses the optimal amount of labor while the firm consequently determines the optimal wage corresponding to that amount of labor given by Equation (6). However, the trade union needs to take into consideration the optimal levels of investment goods chosen by the firm. Therefore, the current value Hamiltonian is of the form:

$$\mathcal{H} = L\frac{\partial f}{\partial y} + \mu_1\left(\frac{\lambda_K - p_K}{2} - \delta K\right) + \mu_2\left(\frac{\lambda_P - p_P}{2} - \delta P\right) + \mu_3\left((\rho+\delta)\lambda_K - \frac{\partial f}{\partial x}\right) + \mu_4\left((\rho+\delta)\lambda_P - m\frac{\partial f}{\partial y}\right) \tag{13}$$

The FOCs yield:

$$L = -\frac{\frac{\partial f}{\partial y}}{\frac{\partial^2 f}{\partial y^2}} + \mu_3 \frac{\frac{\partial^2 f}{\partial x \partial y}}{\frac{\partial^2 f}{\partial y^2}} + \mu_4 m \tag{14}$$

$$\frac{d\mu_1}{dt} = (\rho + \delta)\mu_1 - L\frac{\partial^2 f}{\partial x \partial y} + \mu_3 \frac{\partial^2 f}{\partial x^2} + \mu_4 m \frac{\partial^2 f}{\partial x \partial y} \tag{15}$$

$$\frac{d\mu_2}{dt} = (\rho + \delta)\mu_2 - mL\frac{\partial^2 f}{\partial y^2} + \mu_3 m \frac{\partial^2 f}{\partial x \partial y} + \mu_4 m^2 \frac{\partial^2 f}{\partial y^2} \tag{16}$$

$$\frac{d\mu_3}{dt} = -\delta\mu_3 - \frac{\mu_1}{2} \tag{17}$$

$$\frac{d\mu_4}{dt} = -\delta\mu_4 - \frac{\mu_2}{2} \tag{18}$$

We are interested in the impact of automatable capital P on the optimal amount of labor L. Therefore, we need to analyze the sign of the derivative:

$$\frac{\partial L}{\partial P} = -m\frac{\left(\frac{\partial^2 f}{\partial y^2}\right)^2 - \frac{\partial f}{\partial y}\frac{\partial^3 f}{\partial y^3}}{\left(\frac{\partial^2 f}{\partial y^2}\right)^2} + \mu_3 m \frac{\frac{\partial^3 f}{\partial x \partial y^2}\frac{\partial^2 f}{\partial y^2} - \frac{\partial^2 f}{\partial x \partial y}\frac{\partial^3 f}{\partial y^3}}{\left(\frac{\partial^2 f}{\partial y^2}\right)^2} \tag{19}$$

It is evident that if $m = 0$, automatable capital has no effect whatsoever on labor since it cannot substitute labor. Therefore, we set $m = 1$. Should an increase in P cause a decrease in L, the following inequality must hold:

$$\frac{\partial^2 f}{\partial y^2}\left(\mu_3 \frac{\partial^3 f}{\partial x \partial y^2} - \frac{\partial^2 f}{\partial y^2}\right) - \frac{\partial^3 f}{\partial y^3}\left(\mu_3 \frac{\partial^2 f}{\partial x \partial y} - \frac{\partial f}{\partial y}\right) < 0 \tag{20}$$

Let us make the following assumptions (keeping in mind the assumptions from Equation (2)):

$$\frac{\partial^3 f}{\partial y^3} > 0, \frac{\partial^3 f}{\partial x \partial y^2} < 0 \tag{21}$$

These assumptions are in accordance with the most commonly used production function – the Cobb-Douglas production function – of the form:

$$f(x, y) = x^\alpha y^{1-\alpha}, \alpha \in (0, 1) \tag{22}$$

For this production function, we obtain:

$$\frac{\partial^3 f}{\partial y^3} = (1-\alpha^2)\alpha x^{\alpha} y^{-\alpha-2} > 0, \frac{\partial^3 f}{\partial x \partial y^2} = -\alpha^2(1-\alpha)x^{\alpha-1}y^{-\alpha-1} < 0 \tag{23}$$

Let us now analyze Equation (20) with respect to the sign of μ_3. If $\mu_3 = 0$, then automatable capital has a negative effect of the optimal amount of labor if the following inequality holds:

$$\left(\frac{\partial^2 f}{\partial y^2}\right)^2 > \frac{\partial^3 f}{\partial y^3}\frac{\partial f}{\partial y} \tag{24}$$

It can be verified that this inequality holds true in the Cobb-Douglas case when $\alpha > \frac{1}{2}$. If $\mu_3 > 0$, then it is sufficient that require that the following be true:

$$\mu_3 \frac{\partial^2 f}{\partial x \partial y} > \frac{\partial f}{\partial y} \tag{25}$$

In the Cobb-Douglas case, that holds true if $x < \mu_3 \alpha$. If $\mu_3 < 0$, then we obtain:

$$\frac{\partial^2 f}{\partial y^2} > \mu_3 \frac{\partial^3 f}{\partial x \partial y^2} \wedge \frac{\partial^3 f}{\partial y^3}\left(\mu_3 \frac{\partial^2 f}{\partial x \partial y} - \frac{\partial f}{\partial y}\right) > \frac{\partial^2 f}{\partial y^2}\left(\mu_3 \frac{\partial^3 f}{\partial x \partial y^2} - \frac{\partial^2 f}{\partial y^2}\right) \tag{26}$$

We have thus provided sufficient conditions under which an increase in automatable capital decreases the optimal amount of labor. As is evident, the result depends on the sign of the parameter μ_3. The parameter denotes the shadow value the trade union attaches to the shadow value of capital investment. Let us now analyze its equilibrium value. From Equations (14) – (18) we obtain the following result:

$$\mu_3^* = \frac{\frac{\partial f}{\partial y}\frac{\partial^2 f}{\partial x \partial y}}{\frac{\partial^2 f}{\partial y^2} 2\delta K} \tag{27}$$

where $K := \rho + \delta + \frac{\left(\frac{\partial^2 f}{\partial x \partial y}\right)^2}{2\delta \frac{\partial^2 f}{\partial y^2}} - \frac{\frac{\partial^2 f}{\partial x^2}}{2\delta}$. Strictly speaking, the derivatives are equilibrium values as well as they are determined by the equilibrium values of capital, labor and automatable capital. Since we have placed assumptions on their signs, we do not need to consider their exact value in the equilibrium. Depending on the sign of K, the equilibrium value for μ_3^* is either positive or negative. If $K < 0$, then $\mu_3^* > 0$ and it can be checked that the condition given by Equation (25) is satisfied. The other case is not so straightforward to analyze and its meticulous analysis is left as a prospect for further research.

3 Conclusions

In this article, we have analyzed the impact of automation on the decision-making of trade unions. We have constructed a model of the firm and the trade union, which builds on the work by van der Ploeg (1987). We have derived the FOCs for the optimal amount of labor chosen by the trade union. We show that under certain assumptions, automatable capital can have an adverse effect of the optimal amount of labor.

The effect of automatable capital on labor comes down to the sign of μ_3. While the resulting dynamical system could be analyzed numerically, it suffices to calculate the steady-state value of μ_3 numerically, once the magnitudes of the derivatives have been determined. In certain cases, its steady-state value is positive while in other cases the steady-state value is negative.

The work presented here is still in progress. in the future, one could analyze in more economic detail the assumptions under which automatable capital decreases the optimal amount of labor. Furthermore, the assumption of perfect substitutability could be relaxed to see how the conclusions change. One could also analyze the effect of automatable capital on optimal wages as well. Last but not least, a similar analysis could be performed in a growth model of the national economy. The equations of motions for capital and automatable capital would be different and one would also have to take into account the overall labor force, not just the employed as well as unemployment benefits.

Acknowledgement

The paper was written under the research project for young teachers, researchers, and Ph.D. candidates at the University of Economics in Bratislava 'Impact of Trade Unions on the Implementation of Automation Technologies Across European Countries I-23-108-00'.

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