# You have been terminated: Robot Taxation and the Welfare State

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**Abstract**

We present a three sector OLG model with a homogenous output good that is produced with traditional or robot technology. The traditional sector produces with labor and capital, whereas the modern sector employs robots instead of labor. The robotics sector produces robots using the homogenous output good. We find that wages fall with a relative increase in productivity in the modern sector and a decrease in market power of robot suppliers. Falling wages imply that consumption will fall through generations, and a utilitarian government would feel inclined to intervene. We present several welfare policies, from wage subsidies, unemployment benefits, pensions, to a universal basic income. We also show under which conditions, as the economy becomes fully roboterized, it will switch from an exogenous growth model based on TFP to an endogenous growth model due to constant returns with respect to reproducible factors of production.

**JEL Codes:** O40, O33, H11

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# 1 Introduction

We present a three sector OLG model with a homogenous output good that is produced with traditional or robot technology. The traditional sector produces with labor and capital, whereas the modern sector employs robots instead of labor. The robotics sector produces robots using the homogenous output good. We find that wages fall with a relative increase in productivity in the modern sector and a decrease in market power of robot suppliers. Falling wages imply that consumption will fall through generations, and a utilitarian government would feel inclined to intervene. We present several welfare policies, from wage subsidies, unemployment benefits, pensions, to a universal basic income. We also show under which conditions, as the economy becomes fully roboterized, it will switch from an exogenous growth model based on TFP to an endogenous growth model due to constant returns with respect to reproducible factors of production.

# 2 Related Literature

## 2.1 Robots and the labor market

Recent empirical and theoretical literature provides mixed results about the impact of robots on the labor market.

In their study, (Acemoglu & Restrepo, 2017) analyze the effect of the increase in industrial robot usage between 1990 and 2007 on US local labor markets and estimate that one more robot per thousand workers reduces the employment to population ratio by about 0.18-0.34 percentage points and wages by 0.25-0.5. (Frey & Osborne, 2013) find that almost half of the total US population is at risk of being automated over the next two decades.

(Graetz & Michaels, 2018) use panel data on robot adoption within industries in 17 countries from 1993-2007, findings show that robots did not significantly reduce total employment even though they reduced low-skilled workers' share.

(David, 2017) evaluates the risk of job destruction caused by computer technology in Japan. They find evidence that approximately 55% of jobs are susceptible to be carried by computer capital in the next years.

(Dauth, Findeisen, Südekum, & Woessner, 2017) looks into the effects of industrial robots on the careers of individual manufacturing workers and the equilibrium impact on local labor markets in Germany. The important conclusion is that robots do not result in overall job losses unlike the situation in the US, they change the mixture of the aggregate employment in Germany. They estimate losses in the manufacturing sector but this was compensated with the additional jobs in the service sector.

(Dengler & Matthes, 2018) divides the tasks into groups ' routine versus non-routine' with an aim to take look into the substitution potentials of occupations for specifically Germany. When they use 'occupation-level approach', approximately 47% of the employees work in the substitutable occupations in 2013. Base on 'task-based approach', only 15%

of workers are at the risk of being replaced by automation. However, authors emphasize that these are only the technical feasibilities. The link between automation probability and actual employment growth is not clear.

As an another question, (Zhang, 2019) investigates whether the displacement of human worker by robots will widen the wage inequality between the skilled and unskilled labor and conclude that automation does not necessarily widen the wage gap. (Guerreiro, Rebelo, & Teles, 2017) paper show that without changes in the current US tax system, sizeable fall in the cost of automation would lead to a massive rise in income inequality.

## 2.2 Roboterization and the welfare state

Those mixed results lead policy makers to think about several policy suggestions against the 'possible' detrimental effects of automation gain importance. This includes robot taxation, Universal Basic Income, higher education spending, raising the marginal tax rates of high income individuals and etc.

By using DSGE model for the US economy, (Peralta-Alva & Roitman, 2018) looks into the policies to adjust the economy to technology shocks(an automation shock and a drop in the price of capital). Changing the distribution of market income through education and other human capital formation policies or adjusting the incomes through tax cuts/benefits are some of the options depending on the society's preference on equality or higher output. Base on the US education data, financing the higher education spending requires an increase of 2.5 percentage points in the VAT relative to a no-education-policy response baseline. Also, for the 6 percentage income tax cut for the households whose income close to median is equivalent to 2.5 percentage points increase in the VAT rate.

(Goolsbee, 2018) considers fiscal policy thoughts in an Artificial Intelligence intensive economy. In the case where nothing slows the speed of AI adoption and there is a mass job displacement in a short time, there has been a call for Universal Basic Income(UBI). Yet, there are number of challenges associated with negative taxes and UBI as a policy solution. It is likely to expect a sizable drop in labor market participation by low wage earners and worsen the non-participation rate in the economy.

(Guerreiro et al., 2017) ask themselves how should the government policy respond to technological change. They have different attitude towards universal basic income. Their model demonstrate a massive rise in income inequality with a fall in automation costs. This can be reduced by making the tax system more progressive and by taxing the robots but this comes with a price; i.e. efficiency loss. This can be improved with Mirrlesian optimal income tax but as an alternative approach, when the transfer of basic income in place, it is optimal to tax robots as long as there is partial automation.

### 2.3 Robot taxation

Robot tax literature investigates whether it is optimal to tax robots and if yes, what would be the efficient tax rate for it. There are different approaches and conclusions to robot taxation. (Gasteiger & Prettner, 2017) analyses the long-run growth effects of automation in the canonical Overlapping Generations model framework and conclude that it does not lead to positive long-run growth. On the production side, they introduce a robot tax to automation capital and show that at the steady state, it could raise the capital stock. Another paper from (Zhang, 2019) by using canonical specific-factor framework, author concluded that a tax on robots does always improve wage inequality. (Guerreiro et al., 2017) states that it is optimal to tax robots as long as lump-sum transfers and partial automation in place.

(Costinot & Werning, 2018) explore the magnitude of optimal taxes on robots and trade. They find the efficient tax rate on robots ranging from 1% to 3.7%. They take it one step further and ask as the robots get cheaper and cheaper with the improvements in automation, should we tax them more. Despite the government's strict preference for the redistribution and increasing inequality because of automation, authors show that new technologies are associated with lower taxes on firms using those technologies. Lastly, their envelope result is that even if the automation distorts the wages of low skilled workers and redistribution is important for the economy, this does not justify the rationale for taxes and subsidies on innovation to distort technology adoption by firms.

(Thuemmel, 2018) also study the optimal taxation of robots and labor income. Author shows it is optimal to distort robot adoption. The optimal tax for the US is positive and generates small welfare gains.

## 3 The Model

### 3.1 Households

This is an overlapping generations model where households live for two periods. They supply labor when they are young and live from savings when they are old. We normalize the number of households to unity. Utility of the single household is given by

$$U(L_t, C_{t+1}) = u(L_t) + \frac{1}{1+\rho} C_{t+1}, \tag{1}$$

where $\rho > 0$ can be considered a discount rate of time preference. We will apply three different functional forms for the disutility of work, namely no disutility of work, $du(L_t)/dL_t = 0$ or simply $U(L_t) = 0$, linear disutility of work, $u(L_t) = 1 - L_t$, and constant elasticity $u(L_t) = -L_t^{\epsilon+1}/(\epsilon+1)$. In the first period of their lives, households suffer from work (disutility of labor) and save all their wage income and possible government transfers,

$$S_t = w_t L_t + \tau_t^1. \tag{2}$$

In old age, households consume all their savings and possible government transfers,

$$C_{t+1} = (1 + r_t)S_t + \tau^2_{t+1}. \tag{3}$$

It is rather straightforward to collapse the last two equations into a single intertemporal budget constraint,

$$C_{t+1} = (1 + r_t)(w_t L_t + \tau^1_t) + \tau^2_{t+1}. \tag{4}$$

Note that we would have a public pension system with $\tau^1_t = 0$ and $\tau^2_t > 0$ and a universal basic income with $\tau^1_t = \tau^2_t > 0$. We would have a negative income tax with $\tau^1_t = \tau w_t L_t$. We would have unemployment benefits if $\tau^1_t = max(b_t, w_t L_t)$.

Substituting the budget constraint (4) into the utility function (1) and taking derivatives with respect to labor yields the first order condition for household utility maximization,

$$(1 + \rho)u'(L_t) + (1 + r_t)w_t = 0. \tag{5}$$

In the case of no disutility of work, we will be in a corner solution with $L_t = 1$. In the case of linear disutility of work, we obtain $(1 + r_t)w_t = 1 + \rho$, whereas for logarthmic disutility, $u(L_t) = -lnL_t$, we would obtain $(1 + r_t)w_t L_t = 1 + \rho$. The prior has the disadvantage of no reaction of labor supply to wages, whereas the later has a wage elasticity of labor supply of minus unity, essentially holding income constant. We will adopt a constant disutility of labor disutility, for the remainder of the paper, with $u(L_t) = -L_t^{\epsilon+1}/(\epsilon + 1)$ hence the first order condition reads $(1 + r_t)w_t = (1 + \rho)L^\epsilon_t$, which gives a labor supply function of

$$(1 + r_t)w_t L_t = (1 + \rho)L_t^{\epsilon+1}, \tag{6}$$

and results in a labor supply elasticity of $\epsilon$, which is typically between zero and unity, $0 < \epsilon < 1$. This will simplify the budget constraint (4) to

$$C_{t+1} = (1 + \rho)L_t^{\epsilon+1} + (1 + r_t)\tau^1_t + \tau^2_{t+1}. \tag{7}$$

It makes little sense for a government to pay transfers to households who do not have (consumption) expenditures yet, so we will set $\tau^1_t = 0$ in most cases.

### 3.2 The traditional sector

Firms in the traditional sector produce a homogenous output good with labor and capital under constant returns to scale. Without loss of generality, we can therefore normalize the number of traditional firms to unity. Firms hire workers from the household sector and rent capital from the old. Given that this is a two period OLG model, assuming full depreciation of the capital good seems reasonable. Production is given by

$$Y_t = (K^T_t)^\alpha (A_t L_t)^{1-\alpha}. \tag{8}$$

Normalizing the prize of the output good to unity, profits of the traditional firm are given by

$$\pi_t^T = (1-\tau^Y)(K_t^T)^\alpha (A_t L_t)^{1-\alpha} - (1+\tau^W) w_t L_t - (1+\tau^K)(1+r_t) K_t^T, \tag{9}$$

where we have introduced a tax on turnover (VAT), a wage tax (personal income tax) and a capital income tax. As capital fully depreciates within one period, firms are expected to pay for the full capital good and interest, hence the user cost of capital equals the interest factor $1+r_t$. The first order condition with respect to labor yields

$$\frac{d\pi_t^T}{dL_t} = (1-\alpha)(1-\tau^Y)(K_t^T)^\alpha A_t^{1-\alpha} L_t^{-\alpha} - (1+\tau^W) w_t, \tag{10}$$

which should equal zero in optimum and can be simplified to

$$(1-\alpha)(1-\tau^Y) Y_t = (1+\tau^W) w_t L_t. \tag{11}$$

The first order condition with respect to capital reads

$$\frac{d\pi_t^T}{dK_t^T} = \alpha(1-\tau^Y)(K_t^T)^{\alpha-1}(A_t L_t)^{1-\alpha} - (1+\tau^K)(1+r_t), \tag{12}$$

which should equal zero in optimum and can be simplified to

$$\alpha(1-\tau^Y) Y_t = (1+\tau^K)(1+r_t) K_t^T. \tag{13}$$

Substituting (13) and (11) into (9) shows that firms in the traditional sector make zero profits. With constant returns to scale according to (8), the size of the firm is therefore indetermined, and can be either infinitely small or large. For the sake of simplicity, we assume that there is a single firm in the traditional sector operating under perfect competition. Substituting (13) and (11) into (8) allows us to determine relative prices,

$$w_t^{1-\alpha}(1+r_t)^\alpha = \alpha^\alpha (1-\alpha)^{1-\alpha} \frac{1-\tau^Y}{1+\tau^W} \left(\frac{1+\tau^W}{1+\tau^K}\right)^\alpha A_t^{1-\alpha}. \tag{14}$$

### 3.3 Total factor productivity

In contrast to the conventional Solow model, we postulate finite technical progress. In particular, we assume that future total factor productivity (TFP) is an average between current TFP and constant $A^*$,

$$A_{t+1} = (1-\phi_A) A_t + \phi_A A^*. \tag{15}$$

Note that in the long-run, if $A_{t+1} = A_t = A$, we would be obtain $A = A^*$. Dividing both sides by current TFP, we obtain the TFP growth rate of the economy

$$g_A = \phi_A a_t, \tag{16}$$

where $a_t = A^*/A_t - 1$. As time goes to infinity and $A_t$ converges to $A^*$, total factor productivity will cease to grow in the economy, $g_A = 0$.

### 3.4 The modern sector

Firms in the modern sector produce the (very same) homogenous output good with robots and capital under constant returns to scale. Without loss of generality, we can therefore normalize the number of modern firms to unity. Firms rent capital from the old and buy robots from robotics firms, which we will introduce below. Given that this is a two period OLG model, assuming full depreciation of the capital good and robots seems reasonable. Production is given by

$$Z_t = (K_t^M)^\alpha (A_t R_t)^{1-\alpha}. \tag{17}$$

Using the same constant returns to scale technology as in the traditional sector, but with robots instead of workers, we have robots to be perfect subsitutes to labor. Profits of the modern firm are given by

$$\pi_t^M = (1-\tau^Z)(K_t^M)^\alpha (A_t R_t)^{1-\alpha} - (1+\tau^R)p_t R_t - (1+\tau^K)(1+r_t)K_t^M, \tag{18}$$

where we have introduced a tax on turnover (VAT), a capital income tax and a robot tax. Note that whilst it is easy to distinguish a robot tax from a capital income tax in a theoretical model, for all practical purposes, we may not be able to distinguish a robot from a machine, and would have to assume $\tau^R = \tau^K$. We may also have to use the same turnover taxes as in the traditional sector, $\tau^Z = \tau^Y$. The first order condition with respect to capital yields

$$\frac{d\pi_t^M}{dK_t^M} = \alpha(1-\tau^Z)(K_t^M)^{\alpha-1}(A_t R_t)^{1-\alpha} - (1+\tau^K)(1+r_t), \tag{19}$$

which should equal zero in optimum and can be simplified to

$$\alpha(1-\tau^Z)Z_t = (1+\tau^K)(1+r_t)K_t^M. \tag{20}$$

The first order condition with respect to robot adoption reads

$$\frac{d\pi_t^M}{dR_t} = (1-\alpha)(1-\tau^Z)(K_t^M)^\alpha A_t^{1-\alpha} R_t^{-\alpha} - (1+\tau^R)p_t, \tag{21}$$

which should equal zero in optimum and can be simplified to

$$(1-\alpha)(1-\tau^Z)Z_t = (1+\tau^R)p_t R_t. \tag{22}$$

Solving for the price of robots $p_t$, this equation gives a demand function for robots. Substituting (20) and (22) into (18) shows that firms in the modern sector make zero profits. With constant returns to scale according to (17), the size of the firm is therefore indetermined, and can be either infinitely small or large. For the sake of simplicity, we assume that there is a single firm in the traditional sector operating under perfect competition.

### 3.5 The robotics sector

Robots are not standard manufacturing products and certainly require an enormous amount of knowledge and R&D to produce. We therefore asume that there are only a few firms ($n$) supplying robots, who work under imperfect competition (Cournot oligopolists).

Robotics firms use one unit of the output good to transform it into a robot, that can be used in the following period

$$R_{i,t+1} = B_{t+1} X_{i,t}, \tag{23}$$

where $R_{t+1} = \sum R_{i,t+1}$ and $X_t = \sum X_{i,t}$. Profits of a particular robotics firm therefore depend on the discounted revenues from sales in the following period and costs of inputs,

$$\pi_{i,t} = p_t R_{i,t} - (1 + r_t) X_{i,t-1}. \tag{24}$$

Substituting technology and the demand function gives

$$\pi_{i,t} = (1-\alpha)\frac{1-\tau^Z}{1+\tau^R}\frac{Z_t}{R_t}R_{i,t} - (1+r_t)\frac{R_{i,t}}{B_t}. \tag{25}$$

Note that the oligopolistic firm knows that its supply of robots $R_{i,t}$ has an impact on total supply of robots $R_t$ and production in the modern sector $Z_t$, and therefore of the price for the robots $p_t$, hence the first order condition with respect to robot supply yields

$$\frac{d\pi_{i,t}}{dR_{i,t}} = (1-\alpha)\frac{1-\tau^Z}{1+\tau^R}\frac{Z_t}{R_t}(1 + (1-\alpha)\frac{R_{i,t}}{R_t} - \frac{R_{i,t}}{R_t}) - \frac{1+r_t}{B_t}. \tag{26}$$

With $n$ symmetric firms, we will have $R_t/R_{i,t} = n$. In optimum, this first order condition should equal zero, so that we obtain robot supply,

$$R_t = \eta\frac{1-\tau^Z}{1+\tau^R}\frac{B_t Z_t}{1+r_t} \tag{27}$$

where $\eta = (1-\alpha)(1-\alpha/n)$. In the case of a monopolist supplier, this would reduce to $(1-\alpha)^2$, which is the well known result of double marginalization. We can also derive the Amoroso-Robinson rule for mark-up pricing,

$$p_t = (1-\alpha)(1+r_t)\frac{1}{\eta B_t}. \tag{28}$$

As the number of robotics firms goes to infinity and market power vanishes, the price of robots will equal the user cost of capital, $1 + r_t$.

Just like for total factor productivity, we assume that productivity in robotics is finite,

$$B_{t+1} = (1-\phi_B)B_t + \phi_B B^*. \tag{29}$$

Productivity in robotics will grow at $g_B = \phi_B b_t$, where $b_t = B^*/B_t - 1$ and robotics productivity growth will cease in the long-run, $G_B = 0$.

## 4 Equilibrium

The traditional and the modern sector both produce the same output good, which can be used for consumption, capital and robot investment, so that market clearing reads,

$$Y_t + Z_t = C_t + K_{t+1}^T + K_{t+1}^M + X_t. \tag{30}$$

### 4.1 A purely traditional economy

In the absence of a robotics sector, $Z_t = K_t^M = X_t = 0$ for all $t$, and the model simplifies to a very conventional Solow OLG model. Market clearing (36) will reduce to $K_{t+1}^T = Y_t - C_t$. Substituting traditional technology (8) and the household optimum yields,

$$K_{t+1}^T = (K_t^T)^\alpha (A_t L_t)^{1-\alpha} - \beta u'(L_{t-1}) L_{t-1} - (1 + r_{t-1})\tau_{t-1}^1 - \tau_t^2. \tag{31}$$

Setting first period transfers to zero, $\tau_{t-1}^1 = 0$, this defines a dynamic equation in the capital stock. With constant elasticity of the disutility of work, this simplifies further and simplifies to

$$K_{t+1}^T = (K_t^T)^\alpha (A_t L_t)^{1-\alpha} - \beta \epsilon L_{t-1}^\epsilon - \tau_t^2, \tag{32}$$

Dividing both sides by $K_t^T$ gives the growth factor of the purely traditional economy,

$$1 + g_K = \left( \frac{K_t^T}{A_t L_t} \right)^{\alpha - 1} - \frac{\beta \epsilon L_{t-1}^\epsilon + \tau_t^2}{K_t^T}, \tag{33}$$

As the capital stock in the economy grows, the second term converges to zero. In this case, however, pension payments will be come more and more negligant with respect to income, so we may want to assume transfers proportional to income, $\tau_t^2 = \tau Y_t$. In this case the long run equilibrium growth rate of the capital stock (33) will change to

$$1 + g_K = (1 - \tau) \left( \frac{K_t^T}{A_t L_t} \right)^{\alpha - 1}. \tag{34}$$

Along a balanced growth path we must have $g_K = g_A + g_L$, and substituting this into the production function, we also obtain $g_Y = g_K$. From the first order condition of households (6) we obtain $g_W = \epsilon g_L$, and subsituting this into the first order condition for labor (11) yields $g_Y = (1+\epsilon) g_L$. Substituting this into the balanced growth rate of output, we find $g_Y = [(1+\epsilon)/\epsilon] g_A = [(1+\epsilon)/\epsilon] \phi_A a_t$, which is zero in the long-run. Subsitutiting tradtitional technology (8) and the first order condition with respect to capital (13) gives

$$1 + r^T = \frac{\alpha}{1 - \tau} \frac{1 - \tau^Y}{1 + \tau^K}. \tag{35}$$

This ensures that the interest rate is constant along the balanced growth path. Expectedly, a higher tax on capital and output of the traditional sector both reduce the interest rate. Note that an increase in pensions $\tau$ also reduces the interest rate, thus making work less attractive for private savings.

### 4.2 A purely roboterized economy

In an economy that uses only the modern technology, labor demand falls to zero, implying $w_t = 0$. Hence, with the exception of the $n$ dynasties that own a robotics company[1], consumption will depend solely on government transfers, $C_t = \tau_t^2$. The market clearing condition (36) therefore reduces to

$$K_{t+1}^M + R_{t+1} = Z_t - \tau_t^2. \tag{36}$$

Eliminating $Z_t$ by substituting (20) into (27) gives a constant proportion of robots and capital in production,

$$R_t = \frac{\eta}{\alpha}\frac{1+\tau^K}{1+\tau^R} B_t K_t^M, \tag{37}$$

Substituting this into market clearing (36) and once again assuming that transfers are proportional to income $\tau_t^2 = \tau Z_t$, we obtain a dynamic equation in the capital stock,

$$\left(1 + \frac{\eta}{\alpha}\frac{1+\tau^K}{1+\tau^R} B_t\right) K_{t+1}^M = (1-\tau)\left(\frac{\eta}{\alpha}\right)^{1-\alpha}\left(\frac{1+\tau^K}{1+\tau^R}\right)^{1-\alpha} (A_t B_t)^{1-\alpha} K_t^M. \tag{38}$$

which identifies the growth factor of the capital stock $K_{t+1}^M / K_t^M = 1 + g_K$. From (37) we know that this is identical to the growth factor in robots, and from (17) to output, $g_K = g_R = g_Z$. Even in the absence of technical progress $A_t = B_t = 1$, the economy will exhibit long-run endogenous growth due to constant returns to scale with respect to reproducible factors of production, $g_Z > 0$.

We can show that the derivative of the growth factor with respect to $\eta$ is positive iff $\alpha(1+\tau^K) > n(\tau^K - \tau^R)$. A sufficient condition is that robot taxes are not lower than capital taxes, and this should be easily satisfied. In this case we can easily proof that an increase in competition in the robotics sector will foster economic growth $dg_K/dn > 0$. Differentiated taxes on capital and robots would have an impact. Whilst an increase in the tax on capital income has a positive impact on growth, an increase in the tax on robots will have a negative impact. This result is due to the fact that either will shift resources away from the inefficient robotics sector to the effcient capital goods sector. Finally, a reduction in transfers to households would obviously spur economic growth. In the extreme case $\tau = 0$ we would live[2] in an economy where robots use machines to produce more robots and machines[3].

[1] We will abstract from these for the moment.

[2] or probably not even

[3] The image that comes to mind is the future described in the Terminator movies.

### 4.3 The mixed economy

Substituting the modern technology expansion path (37) into modern technology (17) gives

$$Z_t = K_t^M \left(\frac{1+\tau^K}{1+\tau^R}\right)^{1-\alpha} \left(\frac{\eta}{\alpha}\right)^{1-\alpha} (A_t B_t)^{1-\alpha}. \tag{39}$$

Unless robots are taxed differently from capital, taxes have no influence on the capital to output ratio in the modern economy. We can now derive the interest factor from the first order condition for capital in the modern economy (20),

$$1 + r_t^M = \frac{1-\tau^Z}{1+\tau^K} \left(\frac{1+\tau^K}{1+\tau^R}\right)^{1-\alpha} \alpha^\alpha \eta^{1-\alpha} (A_t B_t)^{1-\alpha}. \tag{40}$$

This is the demand function for capital goods in the modern sector, and it turns out to be perfectly elastic. If interest rates in the traditional sector are higher than the above, no capital will be invested in the modern sector, and the economy will be purely traditional. As interest rates in the modern sector increase, they will slowly siphon capital away from traditional firms, increasing their marginal product of capital (13), until at one point the traditional sector disappears. Once we know the interest rate from above, we can actually compute the capital stock in the traditional sector (13), as the return to capital should be identical across sectors,

$$K_t^T = \frac{1-\tau^Y}{1-\tau^Z} \left(\frac{1+\tau^R}{1+\tau^K}\right)^{1-\alpha} \left(\frac{\alpha}{\eta}\right)^{1-\alpha} (A_t B_t)^{\alpha-1} Y_t. \tag{41}$$

#### 4.3.1 The rise of the machines

In the absence of a disutility of work, and if the traditional sector is in steady-state, we can actually identify the advent of the singularity[4], when a fully roboterized sector starts to emerge ($r^M \geq r^T$),

$$A_t B_t \geq \frac{\alpha}{\eta} \left(\frac{1+\tau^R}{1+\tau^K}\right) \left(\frac{1-\tau^Y}{1-\tau^Z}\right)^{\frac{1}{1-\alpha}} (1-\tau)^{\frac{1}{\alpha-1}}. \tag{42}$$

Higher taxes on the modern sector with respect to the traditional sector, and higher taxes on robots with respect to capital will delay the emergence of a modern sector. A decrease in transfers to the old and an increase in competition in the robotics sector will boost roboterization. Productivity gains, both in the general economy ($A_t$) and in the robotics sector ($B_t$) will make fully automated production more likely. However, an increase in the economywide productivity growth rate $g$ delays roboterization.

[4]The singularity actually occurs not when fully automated production starts, but when computers become self aware. We apologize for this imprecision here. As fans of the Terminator movie know, it took Skynet a mere two hours and 14 minutes to become self-aware on Judgement Day, August 4, 1997.

### 4.3.2 Hasta la vista

We can now substitute the capital stock of the traditional sector from (41) into traditional technology (8) to obtain

$$Y_t = \left(\frac{1-\tau^Y}{1-\tau^Z}\right)^{\frac{\alpha}{1-\alpha}} \left(\frac{1+\tau^R}{1+\tau^K}\right)^{\alpha} \left(\frac{\alpha}{\eta}\right)^{\alpha} A_t^{1-\alpha} B_t^{-\alpha} L_t. \tag{43}$$

Productivity $A_t$ has two effects on traditional output. First, it directly increases output, and this will increase production proportionally. Second, it increases productivity in the modern sector, and this will allocate more ressources to the modern sector, thus reducing production of the traditional sector. It is important to note that the traditional sector will shrink as productivity in the robotics sector $B_t$ increases, but less than proportional, as labor will offset part of the cost disadvantage. Substituting this into the first order condition for labor (11) yields

$$w_t = \frac{1-\tau^Y}{1+\tau^W} \left(\frac{1-\tau^Y}{1-\tau^Z}\right)^{\frac{\alpha}{1-\alpha}} \left(\frac{1+\tau^R}{1+\tau^K}\right)^{\alpha} \left(\frac{\alpha}{\eta}\right)^{\alpha} (1-\alpha) A_t^{1-\alpha} B_t^{-\alpha}. \tag{44}$$

Wages are determined negatively by a tax on labor ($\tau^W$), capital ($\tau^K$), and a tax on the traditional sector ($\tau^Y$), and positively by a tax on robots ($\tau^R$) and the modern sector ($\tau^Z$). If we cannot distinguish between a capital income and a robot tax ($\tau^K = \tau^R$), robot taxes have no impact whatsoever on wages. Even if we cannot differentiate between turnover taxes in the modern and tradtional sectors ($\tau^Z = \tau^Y$), a turnover tax (or VAT) would reduce wages, whereas a reduction in labor taxes would boost wages.

A decline in the mark-up in the robotics sector would actually reduce wages, so fostering competition in these sectors will be detrimental to wage income. Most importantly, productivity gains in the economy, and hence also in the traditional sector, increase wages, whereas productivity gains in the robotics sector would lead to falling wages. When wages fall below a threshold imposed by a reservation wage, the traditional sector will close down and the economy will be run entirely by the modern technology based on robots and capital, but not work.

Having identified interest rates (40) and wages (44) of the mixed economy, we can derive employment from the household first oder condition (6),

$$L_t^{\epsilon} = \frac{\alpha(1-\alpha)}{1+\rho} \frac{1-\tau^Y}{1+\tau^W} \frac{1-\tau^Z}{1+\tau^K} \left(\frac{1+\tau^K}{1+\tau^R}\right)^{1-2\alpha} \left(\frac{1-\tau^Y}{1-\tau^Z}\right)^{\frac{\alpha}{1-\alpha}} \left(\frac{\eta}{\alpha}\right)^{1-2\alpha} A_t^{2-2\alpha} B_t^{1-2\alpha}. \tag{45}$$

There are two contrasting effects of robotics productivity $B_t$ on the labor supply decision. First, an increase in robotics productivity will reduce wages and therefore reduce labor supply in favor of leisure. Second, an increase in robotics productivity will boost interest rates and therefore increase life savings, which will encourage households to increase labor supply. The two effects will exactly offset for $\alpha = 1/2$. Labor supply will decline for any $\alpha > 1/2$, and only in this case will robots drive out humans from the workforce. The rise of robots can be the end of work for humans. But obviously, in this case also the end of first period income, and hence consumption. More than the end of work, it could bring about the end of men, unless government intervenes. Paraphrasing Lincoln Steffens, we have seen the future, and it doesn't work.

# 5 Taxation and the Welfare State

In order to be able to tax robots, we need to be able to define the tax base, or what constitutes a robot. The International Organisation for Standardisation (2012) defines an industrial robot 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". This definition has also been taken up by the International Federation of Robotics. Kaplan (2015) defines robotic systems as "sensors and actuators that can see, hear, feel (touch), smell, [taste] and interact with their surroundings". The EU Parliament (2017) defines smart robots as "the acquisition of autonomy through sensors and/or by exchanging data with its environment (interconnectivity) and the trading and analysis of those data; self-learning from experience and by interaction (optional criterion); at least a minor physical support; the adaptation of its behaviour and actions to the environment; and the absence of life in the biological sense".

All three definitions give the reader a clear idea what constitutes a robot. However, they are of little practical use when it comes to taxation, as an inverted Turing test, that we have devised can show: Under all of the above defintions, a modern car could be classified as a robot, whereas your typical Star Wars Fifth Class Service Droid (GNK Series) would be able to escape the definition. If robots are programmed to tell the truth, self-declaration would work. But robots programmed to maximize profits would certainly self-declare as a simple machine if robots are taxed higher than machines. For all practical purposes, we will therefore assume that a robot cannot be differentiated from capital, and hence we will assume $\tau^R = \tau^K$ and $\tau^Z = \tau^Y$.

**Proposition 1** *With exogenous technical progress, the rise of the modern sector cannot be blocked. It can be slowed down by a decline in competition in the robotics sector* ($n$) *and an increase in transfers* ($\tau$)*.*

An decrease in the number of robotics providers will increase the mark-up for robots, and this makes modern technology more costly, and traditional technology can prevail for longer. By contrast, an increase in proportional transfers introduces a tax wedge in capital accumulation, leading to an increase in the interest rate of the traditional sector, and thus rendering investment in traditional technology profitable for longer. Both results can be immideately observed from equation (42).

Instead of preventing the emergence of a modern sector, politics may simply aim at reducing the use of robots within modern technology. With the excemption of reducing competition in the robotics sector, and a legal ban, there is little that can be achieved through taxation, as can be observed from equation (37). The same holds for ambitions to stop the decline of the traditional sector, equation (43).

**Proposition 2** *Lower taxes on wages and output (of the traditional sector) will foster wages, just like a decline in competition of the robotics sector.*

An reduction in the tax on labor will obviously increase the after-tax real wage. Interestingly, a reduction in the tax on output of the traditional sector will increase of the amount of income distributed to workers and thus improve wages, despite the fact that this will also happen in the modern sector contemporaneously, given $\tau^Z = \tau^Y$.

The real issue is of concern over the impact of robots on employment. Here, our results depend crucially on the supply of labor.

**Proposition 3** *There is no revenue neutral tax reform that can stop the decline of employment in a roboterized economy.*

The decline of employment can be reduced by reducing taxes on wages and traditional output, as both increase the after tax real wage, and by reducing taxes on modern output and capital, as both increase the real interest rate that compound savings and render working more attractive. Employment increases as the compounded savings for future consumption increases, equation (6). As labor taxes and taxes on output of the traditional sector reduce wages, they will also reduce employment. A tax on capital and on output of the modern sector will reduce interest rates, and thus reduce the future value of savings, thereby leading to lower employment.

**Proposition 4** *Under a Rawlsian welfare concept*[5] *welfare depends positvily on work and welfare,*

*Proof:* Substituting the household first order condition (6) into the budget constraint (4), we find that utility depends only on employment and transfers,

$$U(C_{t+1}, L_t) = \frac{\epsilon}{\epsilon + 1} L_t^{\epsilon+1} + \frac{\tau}{1+\rho}(Y_{t+1} + Z_{t+1}). \tag{46}$$

Having a job may be just as important as receiving welfare payments, so any form of taxation that improves employment (45) is an improvement to living in a robot age.

[5]We assume that the owners of robotics firms are supplying labor just like everyone else, but also receiving revenues from their oligopolistic companies, and are thus richer than the rest of the population.

## 6 Conclusions

We have presented a three sector OLG model with a homogenous output good that is produced with traditional or robot technology. The traditional sector produces with labor and capital, whereas the modern sector employs robots instead of labor. The robotics sector produces robots using the homogenous output good. We find that wages fall with a relative increase in productivity in the modern sector and a decrease in market power of robot suppliers. Falling wages imply that consumption will fall through generations, and a utilitarian government would feel inclined to intervene. We present several welfare policies, from wage subsidies, unemployment benefits, pensions, to a universal basic income. We also show under which conditions, as the economy becomes fully roboterized, it will switch from an exogenous growth model based on TFP to an endogenous growth model due to constant returns with respect to reproducible factors of production.

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