Freie Universität Berlin

A Note on Automation, Stagnation, and the Implications of a Robot Tax

Emanuel Gasteiger
Klaus Prettner

School of Business & Economics

Discussion Paper

Economics

2017/17

A Note on Automation, Stagnation, and the Implications of a Robot Tax

Emanuel Gasteiger[a,b] and Klaus Prettner[c*]

a) Freie Universität Berlin,
School of Business & Economics,
Boltzmannstraße 20
14195, Berlin, Germany
email: emanuel.gasteiger@fu-berlin.de

b) Instituto Universitário de Lisboa (ISCTE-IUL),
Business Research Unit (BRU-IUL),
Av. das Forças Armadas,
1649-026 Lisboa, Portugal

c) University of Hohenheim
Institute of Economics
Schloss, Osthof-West,
70593 Stuttgart, Germany
email: klaus.prettner@uni-hohenheim.de

Abstract

We analyze the long-run growth effects of automation in the canonical overlapping generations framework. While automation implies constant returns to capital within this model class (even in the absence of technological progress), we show that it does not have the potential to lead to positive long-growth. The reason is that automation suppresses wages, which are the only source of investment because of the demographic structure of the overlapping generations model. This result stands in sharp contrast to the effects of automation in the representative agent setting, where positive long-run growth is feasible because agents can invest out of their wage income and out of their asset income. We also analyze the effects of a robot tax that has featured prominently in the policy debate on automation and show that it could raise the capital stock and per capita output at the steady state. However, the robot tax cannot induce a takeoff toward positive long-run growth.

Keywords: Automation, robots, robot taxes, investment, stagnation, economic growth, canonical overlapping generations model, fiscal policy.

1 Introduction

Automation and its potential economic consequences have caught the attention of economists, policymakers, and the general public over the last few years (see, for example, The Economist, 2014; Brynjolfsson and McAfee, 2016). While the number of industrial robots that replace workers on assembly lines already took off in the 1990s (IFR, 2015) and 3D printing technologies are already used to produce highly customized products like hearing aids and prostheses (Abeliansky et al., 2015), driverless cars and lorries that could revolutionize the transport business are currently being developed and tested. Furthermore, automation is not confined to routine tasks that have long been considered as susceptible to replacement by machines: devices based on machine learning are starting to beat doctors in the accuracy of diagnosing diseases, reporters in the speed of writing newsflashes, and even authors in writing books – at least for given parameters of content and style (see Barrie, 2014).

On the one hand, there is widespread agreement that automation has a huge potential to raise economic well-being (Steigum, 2011; Acemoglu and Restrepo, 2015; Graetz and Michaels, 2015; Hémous and Olsen, 2016; Abeliansky and Prettner, 2017; Prettner, 2017). On the other hand, there are also concerns that automation could (at least partly) be responsible for stagnating wages of low-skilled workers, a phenomenon that we have observed in the United States over the past few decades (Frey and Osborne, 2013; Mishel et al., 2015; Arntz et al., 2016; Murray, 2016; Acemoglu and Restrepo, 2017; Prettner and Strulik, 2017). As a consequence, automation might be a major driver of the rise in inequality that has been observed in many countries (Piketty and Saez, 2003; Piketty, 2014). On top of that, by relying on a numerical analysis, it has even been argued that automation could lead to economic stagnation in the long run (Sachs and Kotlikoff, 2012; Benzell et al., 2015; Sachs et al., 2015).

We aim to contribute to this debate along two lines. First, we show analytically that the long-run economic growth effects of automation crucially depend on the underlying framework that is used to describe the process of saving and investment. While the standard neoclassical growth models of Solow (1956), Cass (1965), Koopmans (1965), and Diamond (1965) lead to remarkably similar predictions with regards to the growth effects of household's savings behavior and investment decisions, they lead to diametrically opposed predictions with regards to the growth effects of automation. Models of automation based on Solow (1956), Cass (1965), and Koopmans (1965), in which households save a part of their wage income *and* a part of their asset income, imply that automation could lead to perpetual long-run growth even without (exogenous or endogenous) technological progress. However, models of automation based on the canonical overlapping generations (OLG) framework of Diamond (1965), in which households save *exclusively* out of wage income, imply economic stagnation in the face of automation. The reason for the differential effects of automation between the two types of underlying growth models is rooted in the demographic structure and the implied timing of events in the OLG model. The generation

that builds up its assets for retirement can save *only* out of wage income. The resulting assets are in turn used to invest in standard physical capital and in automation. Since automation is, by its very definition, a substitute for labor, its accumulation suppresses wages and therefore diminishes the only source of investment. As a result, automation is – in a sense – digging its own grave and preventing the takeoff to long-run growth in the OLG economy.

Our second contribution is that we analyze the effects of a robot tax coupled with a redistribution of the proceeds of the tax from robot income to labor income in the OLG setting. We trace the effects of such a tax-transfer scheme on the steady-state capital stock and therefore on steady-state per capita output. While we show that such a tax-transfer scheme cannot overcome the stagnation steady state, it has a positive effect on the per capita capital stock and on per capita output. In the potential implementation of such a scheme, however, we argue that it is important to coordinate with other countries. The reason is that moving capital to jurisdictions without robot taxes is easily done in a world of open economies.

The paper is structured as follows. In Section 2, we sketch out the basic formulation of the OLG model with automation, in Section 3 we analyze the equilibrium dynamics and show that such a model necessarily leads to long-run stagnation. In Section 4 we analyze the effects of a robot tax on the dynamics of the model and on the steady-state capital stock. In Section 5 we summarize and draw conclusions for policy makers.

2   Automation in the canonical OLG framework

Consider an economy in which time $t \in [0, 1 \ldots \infty)$ evolves discretely and households live for three time periods, youth, adulthood, and retirement. Children do not make any economic decisions and fulfill their needs via the consumption expenditures of their parents. Adults supply their available time on the labor market for the market clearing wage w_t and save for retirement. Retirees do not work and finance their consumption expenditures at old age out of their savings carried over from adulthood. The number of children is denoted by n such that the evolution of the population size is exogenous and given by $N_{t+1} = (1 + n)N_t$, where N_t refers to the size of the adult cohort at time t.

Following Diamond (1965), households derive utility from consumption in adulthood, $c_{1,t}$, and from consumption in retirement, $c_{2,t+1}$. Assuming a logarithmic utility function to guarantee analytical tractability and that households discount the future at rate ρ, which implies a discount factor of $\beta = 1/(1 + \rho)$, the household's lifetime utility is given by

$$U_t = \log(c_{1,t}) + \beta \log(c_{2,t+1}). \tag{1}$$

Denoting the real interest rate on savings between time t and time $t+1$ by r_{t+1}, the budget

constraint of households is standard and given by

$$c_{1,t} + \frac{c_{2,t+1}}{1 + r_{t+1}} = w_t, \tag{2}$$

where the left-hand side refers to discounted lifetime consumption expenditures and the right-hand side to lifetime labor income. Solving the households' intertemporal optimization problem yields the consumption Euler equation

$$\frac{c_{2,t+1}}{c_{1,t}} = \beta(1 + r_{t+1}) \tag{3}$$

describing the optimal individual consumption growth path for a given interest rate and a given discount factor. From this expression and the budget constraint, optimal consumption and savings of adults follow as

$$c_{1,t} = \frac{1}{1 + \beta} w_t, \qquad s_t = \frac{\beta}{1 + \beta} w_t. \tag{4}$$

Note that adults consume and save a fraction of their wage income in the first period, which allows them to build up assets for consumption when retired. However, young adults do not yet have any asset income that they could save, which stands in contrast to the models of Solow (1956), Cass (1965), and Koopmans (1965), where individuals start to accumulate assets at the first moment of their life.

While the consumption side is identical to the standard canonical OLG model, the production side changes in a fundamental way in the face of automation. There are now three production factors: labor, which is supplied by adults on the labor market, traditional physical capital in the form of machines, assembly lines, factory buildings, etc., which is an *imperfect* substitute for labor, and automation capital in the form of industrial robots, 3D printers, devices based on machine learning, etc., which is, by its very definition, a *perfect* substitute for labor (see, for example, the definition of automation in Merriam-Webster, 2017). When investing their savings, households can choose to buy traditional physical capital or automation capital.

The representative firm has access to a production technology as described by Prettner (2017)

$$Y_t = K_t^\alpha (N_t + P_t)^{1-\alpha}, \tag{5}$$

where Y_t denotes aggregate output (GDP), K_t denotes the stock of traditional physical capital, P_t denotes the stock of automation capital, and $\alpha \in (0, 1)$ is the elasticity of output with respect to traditional physical capital. This production function conceptualizes the distinctive feature of automation capital as a perfect substitute for labor, which conforms to its very definition.

We assume that there is perfect competition in goods and factor markets such that all three production factors are paid their marginal value products. Using aggregate output

as the numéraire, the profits of the representative firm are given by

$$\Pi_t = K_t^\alpha (N_t + P_t)^{1-\alpha} - w_t N_t - R_t^k K_t - R_t^p P_t, \tag{6}$$

where R_t^k is the rate of return on traditional physical capital and R_t^p is the rate of return on automation capital. The first term on the right-hand side is the revenue of the representative firm, whereas the last three terms are the costs of production in terms of the wage bill ($w_t N_t$), the expenses for traditional physical capital ($R_t^k K_t$), and the expenses for automation capital ($R_t^p P_t$). Profit maximization then implies the following factor rewards

$$w_t \overset{!}{=} R_t^p = (1 - \alpha) \left(\frac{K_t}{N_t + P_t} \right)^\alpha, \tag{7}$$

$$R_t^k = \alpha \left(\frac{N_t + P_t}{K_t} \right)^{1-\alpha}. \tag{8}$$

We observe that, similar to the standard Diamond (1965) model, an increase in traditional physical capital raises the wage rate because it raises the machine intensity of the economy and therefore the productivity of workers. However, an increase in automation capital has the opposite effect because automation capital competes closely with workers. As a consequence, an increase in the stock of automation capital does not raise worker's productivity as measured by their marginal value product but renders the workers more and more redundant.[1]

3 Equilibrium and main results

For low levels of the traditional capital stock and for low levels of automation capital, Equations (7) and (8) imply

$$\lim_{P_t \to 0} R_t^p = (1 - \alpha) \left(\frac{K_t}{N_t} \right)^\alpha \qquad \text{and} \qquad \lim_{K_t \to 0} R_t^k = \infty. \tag{9}$$

This means that the Inada condition is not fulfilled for automation capital such that the possibility of a corner solution emerges. If the traditional capital stock and the automation capital stock are close to zero, individuals would only want to invest in the accumulation of physical capital because its return is higher. Only later on, for a large enough traditional physical capital stock, an interior equilibrium on the capital market becomes feasible. For certain parameters, investments in both types of capital then yield the same rate of return and individuals would start to accumulate both, traditional physical capital and automation capital. Such an interior equilibrium of the capital market is characterized by a no-arbitrage relationship between both types of investment implying that $R_t^k = R_t^p$. From this condition, the following relationship between P_t and K_t can be derived that

---

[1]Note that labor productivity as measured by GDP per worker increases for both an increase in K_t and an increase in P_t. The reason is that an increase in both types of capital implies more production for a given amount of labor input.

holds in an interior capital market equilibrium

$$P_t = \left(\frac{1-\alpha}{\alpha}\right) K_t - N_t. \tag{10}$$

The intuition behind this relationship is best illustrated by referring to Equations (7) and (8): a higher stock of traditional physical capital (K_t) raises the rate of return on investment in automation capital (P_t) and reduces the rate of return on traditional physical capital. Hence, the stock of automation capital has to rise in response to re-establish the equality between the rates of return on traditional physical capital and on automation capital. By contrast, a larger cohort size of adults (N_t) implies that there are more workers available. In light of Equation (7), workers will have lower wages as a result such that the incentives for automation are lower. This reduces the incentives to invest in automation capital, which leads to a reduction in its equilibrium stock (see also Abeliansky and Prettner, 2017, for a theoretical consideration and for empirical support). The behavior of the stock of automation capital can now be illustrated by means of the following equation

$$P_t = \max \left\{ 0, \left(\frac{1-\alpha}{\alpha}\right) K_t - N_t \right\}, \tag{11}$$

which takes into account that households do not invest in automation capital if Equation (10) is negative. In this case the production function collapses to the standard expression in the canonical OLG model as given by $Y_t = K_t^\alpha N_t^{1-\alpha}$ and, consequently, the steady-state per capita capital stock and per capita income are constant.

To solve for the steady state that is associated with an interior equilibrium of the capital market, we plug the no-arbitrage relationship (10) into the production function (5). This yields an AK-type of technology in equilibrium

$$Y_t = \frac{1-\alpha}{\alpha} K_t, \tag{12}$$

where $A \equiv (1-\alpha)/\alpha$. As is well-known, such a production structure usually leads to perpetual growth because there are constant returns with respect to the accumulation of physical capital (see, for example, Romer, 1986; Rebelo, 1991). As far as neoclassical models of automation that admit a representative household along the lines of Solow (1956), Cass (1965), and Koopmans (1965) are concerned, there is indeed the possibility of perpetual long-run growth for exactly this reason (see Steigum, 2011; Prettner, 2017). It is important to note that this result holds true for a constant level of technology and it is not the result of knowledge spillovers due to a learning-by-doing mechanism. Instead, it follows directly from the feature of automation that it is a substitute for labor, which prevents the diminishing returns from capital accumulation from kicking in. As a consequence, the standard neoclassical convergence mechanism toward a steady state in which the economy stagnates is not operative.

As we show next, the fact that our OLG model with automation exhibits an AK-type

of technology in case of an interior capital market equilibrium does not imply sustained growth. This stands in sharp contrast to the described findings of Steigum (2011) and Prettner (2017) for the representative agent neoclassical growth model with automation. Since the economy is closed and we follow the standard practice in OLG models by assuming that both types of capital fully depreciate over the course of one generation, the aggregate stock of assets at time $t + 1$ is determined by investment in period t. This implies that we have the following law of motion for the aggregate stock of assets

$$S_t = s_t N_t \overset{!}{=} K_{t+1} + P_{t+1} = \frac{\beta(1-\alpha)}{1+\beta} \left(\frac{K_t}{N_t + P_t} \right)^\alpha N_t. \tag{13}$$

We are now at the stage at which we can define a competitive equilibrium of the economy in case of an interior capital market equilibrium as follows.

Definition 1. *A competitive equilibrium is a sequence $\{K_t, P_t, c_{1,t}, c_{2,t}, R_t, R_t^k, R_t^p, w_t\}_{t=0}^\infty$, such that $\{R_t, R_t^k, R_t^p, w_t\}_{t=0}^\infty$ satisfy (7), (8), and $R_t = R_t^k = R_t^p$, $\{c_{1,t}, c_{2,t}\}_{t=0}^\infty$ satisfy (3) and (4), $\{K_t, P_t\}_{t=0}^\infty$ satisfy (10) and (13), and $\{N_t\}_{t=0}^\infty$ satisfies the population growth equation $N_{t+1} = (1 + n)N_t$.*

Dividing Equation (13) by the size of the adult cohort N_{t+1} and plugging in the aggregate production function (5) and the no-arbitrage condition (10), we arrive at the steady-state capital-labor ratio of the economy as given by $k_{t+1} = k_t = k$ with

$$k = \alpha + \alpha \left(\frac{\beta}{1+\beta} \right) \left(\frac{1-\alpha}{1+n} \right) \left(\frac{\alpha}{1-\alpha} \right)^\alpha. \tag{14}$$

It is immediately clear that there is no growth in the capital-labor ratio because the right-hand side of Equation (14) consists of constant parameters. In this situation we know from inspecting Equation (12) that GDP per capita stagnates and there is no potential for long-run economic growth. We summarize our main finding on the long-run growth effects of automation in the canonical OLG economy in the following proposition.

Proposition 1. *In the canonical overlapping generations model with automation and an interior capital market equilibrium, where both traditional physical capital and automation capital are accumulated:*

  i) the production structure resembles the properties of an AK type of growth model;

 ii) the accumulation of automation capital reduces wages and therefore the savings/ investments of households;

iii) the economy is trapped in a stagnation equilibrium because of the feedback effect between automation and wages.

This proposition implies that, in contrast to the standard neoclassical growth models with a representative agent, the economy necessarily stagnates in the canonical OLG model even if agents invest in both types of capital. The reason is that investment is fully

financed out of wage income as implied by (4). However, wage income itself is reduced by automation. In a sense, automation is therefore digging its own grave in the OLG model. This result provides an analytical explanation for the numerical findings of Sachs and Kotlikoff (2012), Benzell et al. (2015), and Sachs et al. (2015) in the simplest possible OLG model that allows for closed-form solutions. In the following remark, we provide the solution for the model with exogenously growing technology. The main intuition does not change in the sense that automation does not represent an additional engine of growth on top of technological progress in such a setting.

Remark 1. *When we allow for labor-augmenting technological progress, the production function is given by*

$$Y_t = K_t^\alpha (A_t N_t + P_t)^{1-\alpha}, \tag{15}$$

where technology evolves according to $A_{t+1} = (1 + g)A_t$ with $A_0 = 1$ and $g > 0$. In this case the effective capital-labor ratio $\tilde{k} \equiv K/AL$ is given by

$$\tilde{k} = \alpha + \alpha \left(\frac{\beta}{1+\beta} \right) \frac{(1-\alpha)}{(1+n)(1+g)} \left(\frac{\alpha}{1-\alpha} \right)^\alpha \tag{16}$$

at the steady state. In this case, per capita variables grow along a balanced growth path at the rate of technological progress, g. For $g = 0$, Equation (16) collapses to Equation (14) and the economy is back in the stagnation steady state. In the case with positive long-run growth, our result holds true in the sense that automation does not represent an additional engine for long-run economic growth besides technological progress.

4   The effects of a robot tax

A natural question that emerges in our context is the extent to which redistribution policies can affect the impact of automation on the economy. In particular, a tax on robots is often referred to as a solution to mitigate some of the negative consequences of automation. For example, Bill Gates stated in an interview in 2017 that "[...]taxation is certainly a better way to handle it than just banning some elements of it." Gates also mentions how such a tax could be designed: "Some of it can come on the profits that are generated by the labor-saving efficiency there. Some of it can come directly in some type of robot tax." (Delaney, 2017). Furthermore, some governments and even the European Parliament are ventilating ideas about a robot tax (see, for example Prodhan, 2017). In the context of our model, it might be straightforward to conjecture that a tax on the income generated by robots and an associated redistribution of the proceeds of the tax toward workers who do not own assets could raise aggregate savings and enable the asset-poor parts of the population to participate in the gains that automation brings about. While we show that such a scheme is not effective in overcoming stagnation, the *level* of per capita income can be affected in case of the steady state that is associated with an interior capital market equilibrium.

To conceptualize the tax-transfer scheme, we examine lump-sum transfers to the working age adults denoted by $\bar{\tau}_t$, which are financed by a tax on the use of automation capital for firms (the robot tax) at rate $\tau \in [0, 1]$. The budget constraint of households in the model with taxes and redistribution has to be modified and is given by

$$c_{1,t} + \frac{c_{2,t+1}}{1 + r_{t+1}} = w_t + \bar{\tau}_t, \tag{17}$$

where the lump-sum redistribution adds to the wage rate. The solution of the modified intertemporal optimization problem implies optimal consumption and savings of adults as

$$c_{1,t} = \frac{1}{1 + \beta}(w_t + \bar{\tau}_t), \qquad s_t = \frac{\beta}{1 + \beta}(w_t + \bar{\tau}_t). \tag{18}$$

The profit function of the representative firm in case of the tax-subsidy scheme becomes

$$\Pi_t = K_t^\alpha (N_t + P_t)^{1-\alpha} - w_t N_t - R_t^k K_t - (1 + \tau) R_t^p P_t, \tag{19}$$

which takes into account that a robot tax increases the expenses of the employment of robots versus other types of machines. As a consequence, τ distorts the no-arbitrage condition between using traditional physical capital K_t and automation capital P_t in favor of using traditional capital K_t.

The lump-sum transfers to the each adult are then given by

$$\bar{\tau}_t = \tau R_t^p \left(\frac{P_t}{N_t} \right). \tag{20}$$

Altogether, the steady-state per capita capital stock in case of the tax-transfer scheme can then be calculated as

$$k^\tau = \frac{\alpha \left\{ (1 + \beta)(1 + n)(1 + \tau) + (1 - \alpha)\beta \left[\frac{\alpha(1+\tau)}{1-\alpha} \right]^\alpha \right\}}{\left\{ (1 + \beta)(1 + n)(1 + \alpha\tau) - \alpha^2 \beta\tau(1 + \tau) \left[\frac{\alpha(1+\tau)}{1-\alpha} \right]^{\alpha-2} \right\}}. \tag{21}$$

It is easy to see that, in case of $\tau = 0$, Equation (21) collapses to the steady-state per capita capital stock of the original model as given by Equation (14). At that stage we can state the following result with respect to the effects of the tax-subsidy scheme.

Proposition 2. *In the canonical overlapping generations model with automation and an interior capital market equilibrium, where both traditional physical capital and automation capital are accumulated:*

  i) a robot tax is not effective in overcoming stagnation;

  ii) a robot tax raises per capita capital and thereby per capita income at the steady state.

Proof. Part i) of the proposition follows immediately from inspecting Equation (21), which is constant.

For part ii), note that the derivative of the steady-state per capita capital stock with respect to the robot tax rate is given by

$$
\frac{\partial k^{\tau}}{\partial \tau} = \frac{(1-\alpha)\alpha \left\{ (1-\alpha)\beta(1+\beta)(1+n)\left(1-\tau^2\right)\left[\frac{\alpha(1+\tau)}{1-\alpha}\right]^{\alpha} \right\}}{\left\{ (\alpha-1)^2\beta\tau\left[\frac{\alpha(1+\tau)}{1-\alpha}\right]^{\alpha} - (1+\beta)(1+n)\left(1+\tau\right)\left(1+\alpha\tau\right) \right\}^2}
$$
$$
+ \frac{(1-\alpha)\alpha \left\{ (1+\beta)^2(1+n)^2\left(1+\tau\right)^2 + (\alpha-1)^2\beta^2\left[\frac{\alpha(1+\tau)}{1-\alpha}\right]^{2\alpha} \right\}}{\left\{ (\alpha-1)^2\beta\tau\left[\frac{\alpha(1+\tau)}{1-\alpha}\right]^{\alpha} - (1+\beta)(1+n)\left(1+\tau\right)\left(1+\alpha\tau\right) \right\}^2} > 0. \quad (22)
$$

Since we have that α and τ are both between zero and one, it is easily seen that the numerator in both terms on the right-hand side is positive. From the fact that the denominator is squared, it then follows that the whole derivative is always positive. Consequently, the robot tax raises per capita capital and per capita output at the steady state. $\qquad\square$

Altogether, we see that the robot tax has the potential to raise per capita capital and per capita output at the steady state of the canonical OLG model with automation. However, it has to be cautioned that this result is only derived for a closed economy, where capital in either form cannot move abroad. In an open economy setting, the robot tax faces the same difficulty as a tax on financial transactions (the "Tobin Tax") in the sense that it is very easy to move a mobile production factor to a jurisdiction that does not impose such a tax. A successful implementation of a robot tax then depends on whether or not it is implemented by many countries. In this sense the results of our model could be interpreted to hold for a large entity such as all OECD countries taken together. In case of a joint introduction of the tax in all OECD countries, there might indeed be gains in terms of per capita income.

5 Conclusions

We demonstrate that the canonical OLG model of Diamond (1965) implies economic stagnation even in the face of automation. This holds true despite the fact that the overall production structure resembles the properties of an AK growth model without the diminishing returns of physical capital that are responsible for the standard well-known convergence mechanisms toward a steady-state equilibrium. The reason for stagnation is that, in this framework, households exclusively save out of their labor income. By definition, however, automation competes with labor and depresses the wage rate and therefore labor income. This reduces the savings and investment potential of households and prevents the economy from growing. Our results explain the numerical findings of Sachs and Kotlikoff (2012), Benzell et al. (2015), and Sachs et al. (2015) in the simplest analytically tractable setting. However, the results also illustrate that the phenomenon of stagnation in the presence of automation is not generalizable to other models of capital accumulation in which households also re-invest a fraction of their asset incomes.

We also analyze the effects of a robot tax in this setting and show that it has the potential to raise per capita capital and per capita output at the steady state. However, it cannot overcome the stagnation of the economy. Furthermore, in a realistic setting, the successful implementation of a robot tax is only feasible if it done many countries because of the possibility that capital of either form just moves to jurisdictions in which there is no robot tax. This calls for a strong international collaboration when considering the introduction of robot taxes.

References

Abeliansky, A., Martinez-Zarzoso, I., and Prettner, K. (2015). The Impact of 3D Printing on Trade and FDI. cege Discussion Paper 262.

Abeliansky, A. and Prettner, K. (2017). Automation and demographic change. Hohenheim Discussion Papers in Business, Economics, and Social Sciences 05-2017.

Acemoglu, D. and Restrepo, P. (2015). The Race Between Man and Machine: Implications of Technology for Growth, Factor Shares and Employment. Mimeo.

Acemoglu, D. and Restrepo, P. (2017). Robots and Jobs: Evidence from US Labor Markets. NBER Working Paper No. 23285.

Arntz, M., Gregory, T., and Zierahn, U. (2016). The Risk of Automation for Jobs in OECD Countries. A Comparative Analysis. OECD Social, Employment and Migration Working Papers, No. 189, OECD Publishing, Paris.

Barrie, J. (2014). Computers Are Writing Novels: Read A Few Samples Here. Available at `http://www.businessinsider.com/novels-written-by-computers-2014-11?IR=T` [Accessed at January 22, 2017].

Benzell, S. G., Kotlikoff, L. J., LaGardia, G., and Sachs, J. D. (2015). Robots are us: Some economics of human replacement. NBER Working Paper 20941.

Brynjolfsson, E. and McAfee, A. (2016). *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. Norton & Company.

Cass, D. (1965). Optimum growth in an aggregative model of capital accumulation. *The Review of Economic Studies*, Vol. 32(No. 3):233–240.

Delaney, K. J. (2017). Droid duties: The robot that takes your job should pay taxes, says bill gates. `https://qz.com/911968/bill-gates-the-robot-that-takes-your-job-should-pay-taxes/` [accessed on 06/01/2017].

Diamond, P. A. (1965). National debt in a neoclassical growth model. *American Economic Review*, Vol. 55(No. 5):1126–1150.

Frey, C. B. and Osborne, M. A. (2013). The Future of Employment: How Suscep-
tible are Jobs to Computerisation? available at `https://web.archive.org/web/`
`20150109185039/http://www.oxfordmartin.ox.ac.uk/downloads/academic/The_`
`Future_of_Employment.pdf`.

Graetz, G. and Michaels, G. (2015). Robots at Work. CEPR Discussion Paper 10477.

Hémous, D. and Olsen, M. (2016). The Rise of the Machines: Automation, Horizontal
Innovation and Income Inequality. Mimeo.

IFR (2015). World Robotics. Industrial Robots 2015. International Federation of Robotics.

Koopmans, T. C. (1965). On the concept of optimal economic growth. In *The Econometric
Approach to Development Planning*. Amsterdam: North Holland.

Merriam-Webster (2017). "automation." retrieved on March 3, 2017, from `https://www.`
`merriam-webster.com/dictionary/automation`.

Mishel, L., Gould, E., and Bivens, J. (2015). Wage Stagnation in Nine
Charts. Economic Policy Institute. Url: `http://www.epi.org/publication/`
`charting-wage-stagnation/`.

Murray, K. (2016). Wage Stagnation. SAGE Business Researcher. Url:
`http://businessresearcher.sagepub.com/sbr-1775-101222-2760442/20161107/`
`wage-stagnation`.

Piketty, T. (2014). *Capital in the Twenty-First Century*. The Belknap Press of Harvard
University Press.

Piketty, T. and Saez, E. (2003). Income Inequality in the United States 1913-1998. *The
Quarterly Journal of Economics*, Vol. 118(No. 1):1–39.

Prettner, K. (2017). A note on the implications of automation for economic growth and
the labor share. *Macroeconomic Dynamics*. (forthcoming).

Prettner, K. and Strulik, H. (2017). The Lost Race Against the Machine: Automation,
Education, and Inequality in an R&D-Based Growth Model. Hohenheim Discussion
Papers in Business, Economics, and Social Sciences 08-2017.

Prodhan, G. (2017). European parliament calls for robot law, rejects robot tax. `http://`
`www.reuters.com/article/us-europe-robots-lawmaking-idUSKBN15V2KM` [accessed
on 01/06/2017].

Rebelo, S. (1991). Long-Run Policy Analysis and Long-Run Growth. *Journal of Political
Economy*, Vol. 99(No. 3):500–521.

Romer, P. (1986). Increasing returns and long-run growth. *Journal of Political Economy*,
Vol. 94(No. 5):1002–1037.

Sachs, J. D., Benzell, S. G., and LaGardia, G. (2015). Robots: Curse or blessing? A basic framework. NBER Working Paper 21091.

Sachs, J. D. and Kotlikoff, L. J. (2012). Smart machines and long-term misery. NBER Working Paper 18629.

Solow, R. M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, Vol. 70(No. 1):65–94.

Steigum, E. (2011). *Frontiers of Economics and Globalization: Economic Growth and Development*, chapter 21: Robotics and Growth, pages 543–557. Emerald Group.

The Economist (2014). Immigrants from the future. A special report on robots. *The Economist*, March 27th 2014.

Diskussionsbeiträge - Fachbereich Wirtschaftswissenschaft - Freie Universität Berlin
Discussion Paper - School of Business and Economics - Freie Universität Berlin

2017 erschienen:

2017/1   ARONSSON, Thomas und Ronnie SCHÖB
          Habit Formation and the Pareto-Efficient Provision of Public Goods
          Economics

2017/2   VOGT, Charlotte; Martin GERSCH und Cordelia GERTZ
          Governance in integrierten, IT-unterstützten Versorgungskonzepten im
          Gesundheitswesen : eine Analyse aktueller sowie zukünftig möglicher
          Governancestrukturen und -mechanismen
          Wirtschaftsinformatik

2017/3   VOGT, Charlotte; Martin GERSCH und Hanni KOCH
          Geschäftsmodelle und Wertschöpfungsarchitekturen intersektoraler,
          IT-unterstützter Versorgungskonzepte im Gesundheitswesen
          Wirtschaftsinformatik

2017/4   DOMBI, Akos und Theocharis GRIGORIADIS
          Ancestry, Diversity & Finance : Evidence from Transition Economies
          Economics

2017/5   SCHREIBER, Sven
          Weather Adjustment of Economic Output
          Economics

2017/6   NACHTIGALL, Daniel
          Prices versus Quantities: The Impact of Fracking on the Choice of Climate
          Policy Instruments in the Presence of OPEC
          Economics

2017/7   STOCKHAUSEN, Maximilian
          The Distribution of Economic Resources to Children in Germany
          Economics

2017/8   HETSCHKO, Clemens; Louisa von REUMONT und Ronnie SCHÖB
          Embedding as a Pitfall for Survey-Based Welfare Indicators: Evidence from an
          Experiment
          Economics

2017/9   GAENTZSCH, Anja
          Do Conditional Cash Transfers (CCT) Raise Educational Attainment? A Case
          Study of Juntos in Peru
          Economics

2017/10   BACH, Stefan; Martin BEZNOSKA und Viktor STEINER
           An Integrated Micro Data Base for Tax Analysis in Germany
           Economics

2017/11   NEUGEBAUER, Martin und Felix WEISS
           Does a Bachelor's Degree pay off? Labor Market Outcomes of Academic
           versus Vocational Education after Bologna
           Economics

2017/12   HACHULA, Michael und Dieter NAUTZ
           The Dynamic Impact of Macroeconomic News on Long-Term Inflation
           Expectations
           Economics

2017/13   CORNEO, Giacomo
           Ein Staatsfonds, der eine soziale Dividende finanziert
           Economics

2017/14   GERSCH, Martin; Cordelia GERTZ und Charlotte VOGT
           Leistungsangebote in integrierten, IT-unterstützten Versorgungskonzepten:
           eine Konzeption (re-) konfigurierbarer Servicemodule im Gesundheitswesen
           Wirtschaftsinformatik

2017/15   KREUTZMANN, Ann-Kristin; Sören PANNIER; Natalia ROJAS-PERILLA; Timo
           SCHMID; Matthias TEMPL und Nikos TZAVIDIS
           The R Package emdi for Estimating and Mapping
           Regionally Disaggregated Indicators
           Economics

2017/16   VOGT, Charlotte; Cordelia GERTZ und Martin GERSCH
           Ökonomische Evaluation eines integrierten, IT-unterstützten
           Versorgungskonzepts im Gesundheitswesen: eine ökonomische Analyse von
           E-Health-unterstützten Versorgungsprozessen
           Wirtschaftsinformatik