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Gasteiger, Emanuel; Kuhn, Michael; Mistlbacher, Matthias; Prettner, Klaus

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Emanuel Gasteiger
Michael Kuhn
Matthias Mistlbacher
Klaus Prettner

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Emanuel Gasteiger[a,b,⋆] Michael Kuhn[c] Matthias Mistlbacher[a]
Klaus Prettner[d]

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a) TU Wien, Institute for Mathematical Economics and Statistics,
Wiedner Hauptstr. 8-10, 1040 Wien, Austria

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

c) International Institute for Advanced Systems Analysis (IIASA),
Schlossplatz 1, A-2361 Laxenburg, Austria

d) Vienna University of Economics and Business, Department of Economics
Welthandelsplatz 1, 1020 Vienna, Austria

Abstract

While automation technologies replace workers in ever more tasks, robots, 3D printers, and AI-based applications require substantial amounts of electricity. This raises concerns regarding the feasibility of the energy transition towards mitigating climate change. How does automation interact with conventional capital in driving energy demand and how do taxes on robots and taxes on electricity affect the adoption of robots and AI? To answer these questions, we generalize a standard economic growth model with automation and electricity use. In addition, we augment the model with electricity taxes and robot taxes and show the mechanisms by which these taxes affect automation. We find that an electricity tax serves a similar purpose as a robot tax. However, a robot tax is much more difficult to implement from a practical perspective.

JEL classification: O11, O14, H21, H23.

Keywords: Automation, Robots, Growth, Electricity Use, Energy Taxes, Robot Taxes.

[⋆]Corresponding author: emanuel.gasteiger@tuwien.ac.at.

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1 Introduction

Robots and Artificial Intelligence (AI) have become an integral part of many industries, and tasks previously done by human workers have been and continue to be automated. While this technological advancement has brought significant benefits (cf. Brynjolfsson and McAfee, 2016; Graetz and Michaels, 2018; Acemoglu and Restrepo, 2018), there are concerns that robots and other automation technologies require substantial amounts of electricity, which could compromise the reduction in energy utilisation that is crucial for the mitigation of climate change (cf. Prettner and Bloom, 2020; Creutzig et al., 2022; Abeliansky et al., 2023). For example, Patterson et al. (2021) and Luccioni et al. (2022) estimate that training the large language model GPT-3 required close to 1,300 megawatt-hours of electricity and caused more than 500 tonnes of carbon dioxide equivalent emissions. Overall, however, whether or not automation capital requires more electricity than conventional capital is still debated in the literature (Chen et al., 2022).

In this short contribution, we propose a model that accounts for energy consumption by robots and other forms of automation capital and employ it to explore the relationship between automation capital and traditional capital, including their respective energy intensity and taxation. Specifically, we investigate how taxes on robots and taxes on electricity could affect the adoption of robots and their impact on electricity demand.

Our findings show that electricity taxes can serve as an effective means of reducing the electricity use in production by shifting capital accumulation away from the more energy intensive technology. If automation capital requires more electricity than traditional capital, we additionally show that an electricity tax serves the same purpose as a robot tax. Robot taxes have been discussed as a way of reducing the accumulation of automation capital and, thus, allowing for more human employment and a lower degree of inequality (Delaney, 2017; Prettner and Strulik, 2020; Gasteiger and Prettner, 2022; Guerreiro et al., 2022). However, implementing a robot tax is challenging from a practical perspective, while an electricity tax is easier to administer. Overall, this paper contributes to the ongoing discourse on robots and their taxation, and sheds light on the neglected issue of the use of electricity in the context of automation technologies.

2 Model Description

2.1 Notation and Assumptions

Consider an economy with three production inputs, human labor $L(t)$, traditional physical capital $K(t)$ (machines, assembly lines, production halls, etc), and automation capital $Z(t)$ (industrial robots, 3D printers, etc). Time t evolves continuously and both types of capital depreciate at the rate δ. We assume a representative household, i.e., aggregate and per capita variables coincide. The population size is constant and equivalent to the workforce. Human labor and traditional physical capital are imperfect substitutes, whereas automation capital and human labor are perfect substitutes (Prettner, 2019; Gasteiger and Prettner, 2022). This assumption ensures tractability of the model and is meant to present the benchmark case of full automation. The qualitative findings would not change in case of a comparatively high but imperfect substitutability between automation capital and labor (see Lankisch et al., 2019; Gasteiger and Prettner, 2022). To focus on the main variables of interest (the adjustment of different types of capital to changes in the parameters of the model), we abstract from technological progress, endogenous responses in the energy price, and the use of tax revenues.

2.2 Households

Following Steigum (2011), the representative individual maximizes lifetime utility, which derives from an iso-elastic utility function

$$U_0 = \int_0^\infty e^{-\rho t} \frac{c(t)^{1-\theta} - 1}{1-\theta} dt, \tag{1}$$

where ρ is the time preference rate, $c(t)$ is instantaneous per capita consumption at time t, and θ determines the elasticity of intertemporal substitution. Denoting per capita assets (consisting of automation capital $Z(t)$ and traditional physical capital $K(t)$) by $m(t)$, the flow budget constraint is given by

$$\dot{m}(t) = r(t)m(t) + w(t) - c(t). \tag{2}$$

Intertemporal optimization leads to the well-known Keynes-Ramsey rule for per capita and aggregate consumption

$$\frac{\dot{C}(t)}{C(t)} = \frac{\dot{c}(t)}{c(t)} = \frac{r(t) - \rho}{\theta}, \tag{3}$$

stating that consumption expenditure growth is positive whenever the interest rate (r) overcompensates individuals for their impatience (ρ) and induces them to postpone consumption.

2.3 Production

Following Prettner (2019), output $Y(t)$ is produced according to the production function

$$Y(t) = AK(t)^\alpha [\beta Z(t) + L(t)]^{1-\alpha}, \tag{4}$$

where α is the elasticity of output with respect to traditional physical capital input. Total factor productivity A is constant because we abstract from technological progress. The parameter β re-scales $Z(t)$ in terms of the number of workers. For instance, $\beta = 2$ means that 1 unit of automation capital replaces 2 workers.

A crucial aspect that is often disregarded when analyzing the substitution of robots for workers is that the operation of robots and many other types of capital requires electricity. Their employment is thus associated with additional energy costs. We take this into account and assume that ξ_K is the electricity intensity of a unit of traditional physical capital, while ξ_Z is the electricity intensity of a unit of automation capital.

Using the final good as the numéraire, the profit maximization problem of the representative firm is given by

$$\begin{aligned}\max_{K(t),L(t),Z(t)} \pi(t) \quad &= \quad AK(t)^{\alpha}[\beta Z(t)+L(t)]^{1-\alpha}-w(t)L(t) \qquad (5)\\ &\quad -R_K(t)K(t)-(1+\tau_Z)R_Z(t)Z(t)-(1+\tau_E)P_E[\xi_K K(t)+\xi_Z Z(t)],\end{aligned}$$

where $w(t)$ is the wage rate, $R_K(t)$ and $R_Z(t)$ are the rental rates for traditional physical capital and automation capital, P_E is the price for electricity, and τ_Z and τ_E are the tax rates on robot income and electricity, respectively. Note that electricity alone cannot produce any output but traditional physical capital and automation capital require electricity as a necessary input for production. To keep the analysis simple and focus on the dynamics of interest, we assume that electricity is supplied exogenously. This means that we face an open economy that imports the marginal unit of electricity or, equivalently, imports the natural resource that is needed to produce the marginal unit of electricity (coal, crude oil, or natural gas).

In a perfectly competitive equilibrium, the wage rate, $w(t)$, the rental rate of traditional physical capital, $R_K(t)$, and the rental rate of automation capital, $R_Z(t)$, are given by the marginal products of the corresponding production factors adjusted for their respective tax burdens:

$$w(t)=(1-\alpha)A\left[\frac{K(t)}{\beta Z(t)+L(t)}\right]^{\alpha}, \qquad (6)$$

$$R_Z(t)=\frac{1}{1+\tau_Z}\left\{(1-\alpha)\beta A\left[\frac{K(t)}{\beta Z(t)+L(t)}\right]^{\alpha}-(1+\tau_E)P_E\xi_Z\right\}, \qquad (7)$$

$$R_K(t)=\alpha AK(t)^{\alpha-1}[\beta Z(t)+L(t)]^{1-\alpha}-(1+\tau_E)P_E\xi_K. \qquad (8)$$

Note that the net rates of return to the investor (the interest rates) are given by $r_Z(t)=R_Z(t)-\delta$ and $r_K(t)=R_K(t)-\delta$. Other than electricity production, the economy is closed such that savings are equal to gross investment, $I(t)=S(t)$. Investors decide endogenously how much of their savings they would like to invest in traditional physical capital and how much in automation capital. As long as one of the two investment vehicles delivers a higher rate of return, the other one would not attract any investment. In an interior market equilibrium, both capital stocks are positive and have to yield the same return, which implies that the no-arbitrage condition

$$R_K(t)-\delta=R_Z(t)-\delta=r(t), \qquad (9)$$

holds, where

$$r(t)=\frac{Z(t)r_Z(t)+K(t)r_K(t)}{Z(t)+K(t)}$$

is the interest rate on household assets. Inserting from (7) and (8), defining $\beta Z(t)+L(t)$ as *effective labor* and

$$X(t):=\frac{\beta Z(t)}{\beta Z(t)+L(t)}$$

as the *automation share* in effective labor, we can rewrite (9) as

$$\frac{K\left(t\right)}{Z\left(t\right)}=\frac{\alpha}{1-\alpha}\frac{1+\tau_{Z}}{X\left(t\right)}+\frac{(1+\tau_{E})P_{E}\xi_{K}K\left(t\right)}{\left(1-\alpha\right)X\left(t\right)Y\left(t\right)}\left[\frac{\xi_{Z}}{\xi_{K}}-\left(1+\tau_{Z}\right)\right]. \tag{10}$$

Note that surging electricity costs, caused either by rising prices P_E or an increase in taxes τ_E, lead to an increase in the ratio of traditional physical capital to automation capital if automation capital is sufficiently more energy intensive, i.e., for

$$\frac{\xi_{Z}}{\xi_{K}}>\left(1+\tau_{Z}\right).$$

The intuition is that, if robots are rather energy intensive, an increase in the electricity price or in the electricity tax both imply a substitution of traditional physical capital for automation capital. The reverse holds true if automation capital is not substantially more energy intensive as compared to traditional physical capital. We can therefore state the central result of our paper.

Proposition 1. *An electricity tax reduces the accumulation of automation capital as long as automation capital is more energy intensive than traditional physical capital. Thus, in this case, an electricity tax has comparable effects to a robot tax on the accumulation of different types of capital.*

Proof. Inspecting Equation (10) for the case of $\xi_Z/\xi_K > (1+\tau_Z)$ shows that both, τ_E and τ_Z raise the ratio of traditional physical capital to automation capital. □

The proposition implies that similar effects to a robot tax can be achieved by taxing electricity at $\tau_E > 0$, while leaving $\tau_Z = 0$, as long as robots are more electricity intensive than other forms of capital. If this is not the case, an electricity tax would work so as to increase the accumulation rate of automation capital as compared to traditional physical capital.

3 Conclusion

Accounting for electricity use of automation technologies and of traditional physical capital, we have shown that an electricity tax can serve similar purposes as a robot tax. Since a robot tax is, from a practical perspective, much more difficult to implement than an electricity tax, an electricity tax could be a suitable alternative, particularly because it also allows for addressing the environmental effects of automation.

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