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Electricity Use of Automation or How to Tax Robots?

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ABSTRACT

While automation technologies replace workers in ever more tasks, robots, 3D-printers, and AI require substantial amounts of electricity. How are automation technologies affected by the price of electricity, and how do robot taxes and electricity taxes affect their adoption? To answer these questions, we generalize a standard economic growth model to incorporate 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—that is comparatively easy to implement—can serve a similar purpose as a robot tax.

JEL Classification: O11, O14, H21, H23

1 | Introduction

Robots, 3D printers, 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 utilization 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 1300 MW-hours of electricity and caused more than 500 t of carbon dioxide equivalent emissions. In addition, Chen (2025) shows that in 2024 data centers consumed 415 terawatt hours of electricity, which corresponds to about 1.5% of the world's electricity consumption, and that this amount will double by 2030 largely due to the increased use of AI. Whether or not automation capital requires more electricity than conventional capital is, however, still debated in the literature (Chen et al. 2022; Abeliansky et al. 2024).

In this short contribution, we propose a model that accounts for energy consumption by robots, 3D printers, and AI (to which we refer as automation capital) and employ it to explore the relationships among automation capital, traditional capital, their respective energy intensities, and taxation. Specifically, we investigate how "robot taxes" and taxes on electricity could affect the adoption of automation technologies 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, AI, etc). Time t evolves continuously and both types of capital depreciate at the rate δ. We assume a representative household, that is, 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 automation capital for workers is that the operation of robots and AI requires substantial amounts of electricity. Their use 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

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

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 of 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.

2.4 | Equilibrium and Main Results

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:

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

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

$$R_K(t) = \alpha A K(t)^{\alpha-1}[\beta Z(t) + L(t)]^{1-\alpha} - \left(1+\tau_E\right)P_E\xi_{K}. \tag{8}$$

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

$$R_K(t) - \delta = R_Z(t) - \delta = r(t) \tag{9}$$

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 Equations (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 Equation (9) as

$$\frac{K(t)}{Z(t)} = \frac{\alpha}{1-\alpha}\frac{1+\tau_Z}{X(t)} + \frac{(1+\tau_E)P_E\xi_K K(t)}{(1-\alpha)X(t)Y(t)}\left[\frac{\xi_Z}{\xi_K} - \left(1+\tau_Z\right)\right]. \tag{10}$$

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, that is, for

$$\frac{\xi_Z}{\xi_K} > \left(1+\tau_Z\right).$$

The intuition is that if robots, AI, and other automation technologies 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 results of our paper in the following proposition.

Proposition 1. *If automation capital is more electricity intensive than traditional physical capital:*

- *High energy prices and high electricity taxes both hamper automation.*
- *An electricity tax has comparable effects to a robot tax on the accumulation of the two types of capital.*

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

The proposition implies that, as long as automation capital is more electricity intensive than other forms of capital, (i) high electricity prices reduce automation and (ii) similar effects to a robot tax can be achieved by taxing electricity at a rate $\tau_E > 0$, while leaving robot taxes at $\tau_Z = 0$. The latter effect is interesting particularly because it is much easier to implement an electricity tax than a robot tax.

3 | Discussion

We have shown that an electricity tax serves a purpose similar to a robot tax if automation capital is more energy intensive than traditional physical capital. With current research on the impacts of automation on energy demand focusing on energy use per unit of output rather than capital, there is little direct evidence to go by from the literature. However, the following calculation would suggest that on average industrial robots are indeed associated with an energy intensity in excess of traditional physical capital. Here, we infer from Kennedy (2022, Figure 5a) that for the US, the energy intensity of the total capital stock in manufacturing in 2018 was

$$\frac{20{,}500\,\text{petajoule (PJ)}}{3700\,\text{billion US-\$}} = 5.54\,\text{PJ / billion US-\$},$$

which is equivalent to 1.54 kWh per US-$. According to Barnett et al. (2017), industrial robots have an annual energy consumption of 21,915 kWh / Unit over a lifetime of 14 years on average. Taking an intermediate value of 150,000 US-$ from the 50,000 US-$ to 250,000 US-$ range of robot prices, as reported in https://www.robotopedia.com/articles/industrial-robot-cost, implies a lifetime energy intensity of 306,810 kWh/150,000 US-$ = 2.05 kWh/US-$ for an average industrial robot. This would, indeed, suggest that $\xi_K = 1.54\,\text{kWh / US-\$} < 2.05\,\text{kWh / US-\$} = \xi_Z$ and imply that an electricity tax can double as a robot tax.

At a conceptual level, the finding that an electricity tax may substitute for a robot tax is of particular relevance when thinking about AI-based automation. This is because, while industrial robots can be physically identified and taxed in principle, this is more questionable for the broad-based use of algorithms, which is difficult to measure and for which even ownership is hard to attribute. Here, an electricity tax is appealing in that it allows linking the tax to a clearly measurable base, while having an impact on the allocation of capital that is similar to a robot tax. However, whether the requirement is met that the energy intensity of AI exceeds that of traditional physical capital is more difficult to gauge and would require more extensive empirical research on the attribution of energy usage to the training and running of AI infrastructures. While we need to relegate a robust answer to future research, we can nonetheless draw the following insights into the case that AI is associated with a lower energy intensity per unit than traditional physical capital. In this case, the slowing down of the adoption of AI systems relative to traditional physical capital may be achieved by way of a robot tax but also by a reduction in the electricity tax. However, a reduction in the electricity tax across the board will lead to additional capital investment in both traditional and automation capital and thus increase overall electricity use.

For follow-up research, we suggest (i) estimating the energy requirements of different forms of production processes more accurately as a basis for formulating the condition on the impact of the relevant taxes more clearly; (ii) developing and numerically analyzing a general equilibrium version of the model to understand the wider impacts of energy vs. robot taxes on economic growth and welfare; (iii) integrating into the model a sector that produces capital goods (automation capital and traditional physical capital), while allowing energy intensity to be a choice variable of the firms that produce these capital goods; and finally (iv) including an endogenous energy sector that produces electricity and where prices are formed in line with supply and demand.

4 | Conclusions

Accounting for electricity use of automation technologies and of traditional physical capital, we have shown that electricity prices matter in the decision to automate and that an electricity tax can serve similar purposes as a robot tax if automation capital is more energy intensive than traditional physical capital. Based on available data, we demonstrate that this is likely to be satisfied for the case of industrial robots. From a practical perspective, a robot tax is much more difficult to implement than an electricity tax, implying that the latter could be a suitable alternative, particularly because it also addresses the environmental effects of automation.

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