Environmental Damages and the Prospects for Economic Development

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July 5, 2023

Abstract

We analyze the extent to which the prospects for economic development may relate to the environmental damages associated with economic activities. We consider an economic growth framework in which production activities generate polluting emissions which in turn negatively affect production capabilities, and public-funded abatement is pursued to mitigate such effects. Since the time preference is endogenously related to capital, abatement affects the size of the discount factor through its implications on capital accumulation. We show that the elasticity of the environmental damage affects the optimal tax rate and thus the abatement level, which in turn determines whether the economy will develop along a stagnation or growth regime. This suggests that the cross-country heterogeneity in the environmental damages may explain the different development patterns experienced by industrialized and developing economies.

Keywords: Endogenous Time Preference, Environmental Damage, Optimal Taxation
JEL Classification: O40, Q50
Word count: 1,964

1 Introduction

This paper explores how people's behavioral attributes, as regards their rate of time preference (RTP) or impatience, impact upon the development paths traversed by an economy in a scenario where the production process gives rise to endogenous growth but also generates polluting emissions, and income taxation is used optimally as an instrument to finance public abatement aimed at reducing pollution.

Several studies suggest that the growing concerns for environmental and sustainable outcomes require us to relax the constant RTP assumption (Weitzman, 1994). Different from extant literature which assumes that environmental factors affect either preferences (John and Pecchenino, 1994) or the RTP (Dioikitopoulos et al., 2020), we postulate that the utility function depends only on consumption (Nordhaus, 2013), and that the RTP is a negative function of capital (Strulik, 2012). Despite the above, environmental parameters (the elasticity of damages and the elasticity of pollution with respect to unabated emissions) drive the optimal tax rate, which in turn determines which of the two regimes an economy ends up in: one leading to stagnation and another to sustained growth. Importantly, the existence of these two regimes is a consequence of the RTP being determined by the accumulated capital.

Our results show that an increase in the elasticity of environmental damages will reduce output and therefore encourage raising the income tax rate to finance abatement. But this will have a negative effect on disposable income which will initially reduce capital accumulation and growth. A reduction in the capital stock will increase impatience (the RTP effect) and hence current consumption. However, beyond a certain

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value of the tax rate, the benefits of abatement will show up prominently, and hence capital accumulation and growth will increase. Also, the higher capital stock will make people more patient, increasing growth further via a reduction of the RTP. So, the endogenous RTP makes the growth effect more pronounced in either direction than would have been the case if it was exogenous.

The paper proceeds as follows. The theoretical model is developed in Section 2. Our results are presented in Section 3. Section 4 concludes.

2 The Model

The social planner seeks to maximize social welfare subject to the dynamic evolution of capital $k_t > 0$ and of the time-preference rate $\rho_t > 0$ by choosing consumption, $c_t > 0$ and the tax rate $0 < \tau_t < 1$. Social welfare is the infinite discounted sum of utilities and the instantaneous utility function is given by: $u(c_t) = \frac{c_t^{1-\sigma}}{1-\sigma}$, where $\sigma \neq 1$ is the inverse of the intertemporal elasticity of substitution. The RTP endogenously changes with the capital stock according to the following equation $\rho_t = \bar{\rho} + \rho_0 k_t^{-\eta}$, where $\eta > 0$ determines the speed at which time preference converges from its initial level ρ_0 towards its steady state value $\bar{\rho}$ as the economic grows (Strulik, 2012). Output is produced by a linear technology: $q_t = Ak_t$, where $A > 0$ measures the total factor productivity. Production generates polluting emissions as follows: $e_t = \phi q_t$ where $\phi > 0$ measures the dirtiness of economic activities (Stokey, 1998). By maintaining a balanced budget at any point in time, the government relies upon income taxation to finance pollution abatement $a_t = \tau_t y_t$, resulting in reducing emissions by the amount $\mu_t = \theta a_t$, where $\theta > 0$ measures the environmental effectiveness of abatement (Byrne, 1997). Pollution is a flow variable and coincides with unabated emissions given by the following expression: $p_t = (\frac{e_t}{\mu_t})^\omega$ where $0 < \omega < 1$ is the elasticity of pollution with respect to unabated emissions. Pollution reduces economic production capabilities through the following damage function $d_t = \xi p_t^\chi$ where $\xi > 0$ is a scale parameter and $\chi > 0$ the elasticity of the environmental damage with respect to pollution. Income equals production net of environmental damage as follows: $y_t = \frac{q_t}{d_t}$. The resource constraint implies that income can be allocated to consumption, investment in capital accumulation $i_t = \dot{k}_t$ or government spending $g_t = a_t$, as follows: $y_t = c_t + i_t + g_t$, which implies that capital evolves according to the following equation: $\dot{k}_t = (1 - \tau_t)y_t - c_t$. The growth rate of capital determines an increase in patience since the endogenous RTP expression can be rearranged to show that the RTP decreases with capital accumulation as follows: $\dot{\rho}_t = -\eta(\rho_t - \bar{\rho})\frac{\dot{k}_t}{k_t}$.

Given the initial capital level $k_0 > 0$ and RTP $\rho_0 > 0$, the social planner's maximization problem can be summarized as follows:

$$\max_{c_t,\tau_t} \quad W = \int_0^\infty \frac{c_t^{1-\sigma}}{1-\sigma} e^{-\int_0^t \rho_s ds} dt \tag{1}$$

$$s.t. \quad \dot{k}_t = (1-\tau_t)\left(\frac{\tau_t}{\lambda}\right)^{\frac{\chi\omega}{1-\chi\omega}} Ak_t - c_t \tag{2}$$

$$\dot{\rho}_t = -\eta(\rho_t - \bar{\rho})\frac{\dot{k}_t}{k_t}, \tag{3}$$

where $\lambda = \frac{\phi\xi}{\theta} > 0$ quantifies the relative environmental inefficiency of production with respect to abatement. Note that our specification of emissions and abatement implies that pollution turns out to be constant and equal to $p_t = (\frac{\lambda}{\tau})^{\frac{\omega}{1-\chi\omega}}$, which intuitively increases with the degree of relative environmental inefficiency and decreases with the tax rate. The above problem clearly shows that the tax rate yields non-monotonic effects on disposable income and thus on capital accumulation: on the one hand, a higher tax rate diverts resources away from capital accumulation, while, on the other hand, a higher tax rate allows to finance more abatement which by reducing the environmental damage makes more income available for capital accumulation. The social planner needs to balance these two competing effects by determining the optimal size of the tax rate.

3 BGP Equilibrium

Solving the optimization problem above allows us to characterize the optimal tax rate τ_t^* and the balanced growth path (BGP) equilibrium, along which output, consumption and capital grow at the same common rate $\gamma = \gamma_y = \gamma_c = \gamma_k$ while the tax rate is constant. There results are summarized in the next two propositions.

Proposition 1. *Provided that $\chi < \frac{1}{\omega}$, the optimal tax rate is constant and given by the following expression:*

$$\tau_t = \tau^* = \omega\chi \in [0, 1]. \tag{4}$$

Proposition 2. *Define $\tilde{A} = (1 - \tau^*) \left(\frac{\tau^*}{\lambda}\right)^{\frac{\chi\omega}{1-\chi\omega}} A$ and $\Theta = \frac{\eta\tilde{A}}{1-\sigma}$. Then, there exists a stagnation regime in which the growth rate and the discount factor are respectively given by:*

$$\gamma_s = 0 \qquad \textit{and} \qquad \rho_s^* = \frac{\tilde{A} + \Theta + \sqrt{(\tilde{A} + \Theta)^2 - 4\Theta\bar{\rho}}}{2}. \tag{5}$$

Whenever $\bar{\rho} > (1 - \sigma)\tilde{A}$, there exists also a growth regime in which the growth rate and the RTP are respectively given by:

$$\gamma_g = \frac{\tilde{A} - \bar{\rho}}{\sigma} \qquad \textit{and} \qquad \rho_g^* = \bar{\rho}. \tag{6}$$

Proposition 1 shows that whenever the elasticity of the environmental damage is not too large (i,e., $\chi < \frac{1}{\omega}$) then the (unique and constant) optimal tax rate increases with both the elasticity of pollution and the elasticity of the environmental damage. Intuitively, these two parameters drive the effectiveness of abatement in lowering pollution and thus in making more resources available for capital accumulation, determining the desirability of income taxation.

Proposition 2 states that the optimal tax rate determines which development regime will prevail over the long run by driving the effective productivity $\tilde{A}$. If the condition $\bar{\rho} > (1 - \sigma)\tilde{A}$ is not verified, then the economy will be trapped in a stagnation regime in which the growth rate is zero ($\gamma_s = 0$) such that economic activities remain at subsistence level and the RTP is constant at some level (ρ_s^*) which depends on the optimal tax rate. If the condition is verified instead, then the economy will follow a growth regime in which the growth rate is strictly positive (γ_g) and related to the optimal tax rate while the RTP is constant at a level ($\rho_s^* = \bar{\rho}$) unrelated to the optimal tax rate.

It may be interesting thus to understand whether differences in the tax rate may explain the differences in development patterns between industrialized and developing countries. In order to shed some light on this, we present a simple parametrization of our model. The steady state RTP in the case of long run growth and the total factor productivity are set as $\bar{\rho} = 0.0267$ and $A = 0.0667$ (Strulik, 2012), the elasticity of pollution with respect to unabated emissions as $\omega = 0.74$ (Liddle, 2015), the inverse of the intertemporal elasticity of substitution as $\sigma = 0.5$ (Barro, 2009), while the elasticity of the damage function is varied within the interval $[0, \frac{1}{\omega}]$ to understand how this parameter affects our results. Indeed, a commonly shared view on climate change states that its economic consequences are likely to be highly heterogeneous across countries (Dennig et al., 2015), thus we capture this possibility by considering different values of the elasticity of the damage function. The relative environmental inefficiency of production with respect to abatement is assumed to take one of three values lower than unity to represent the fact that one unit of output allocated to abatement reduces pollution relatively less than the emissions it generates, and specifically we consider $\lambda = \{0.4, 0.5, 0.6\}$.

Figure 1 shows how the optimal tax rate τ^* (left panel) and the growth rate γ (right panel) change with the elasticity parameter, for $\lambda = 0.4$ (dotted curve), $\lambda = 0.5$ (dashed curve) and $\lambda = 0.6$ (solid curve). Clearly, a higher damage elasticity increases the tax rate as it raises the environmental damage generated

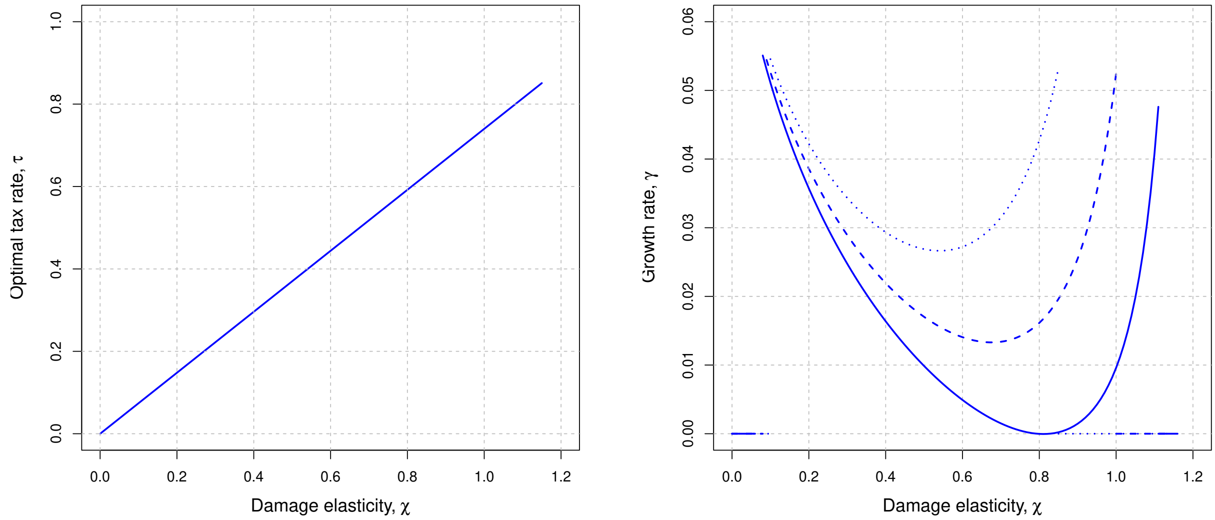

Figure 1: Effects of the damage elasticity parameter χ on the optimal tax rate (left) and on the growth rate (right).

by pollution providing the planner with stronger incentives to abate. However, a higher damage elasticity generates non-monotonic effects on the growth rate and it determines whether the condition $\bar{\rho} > (1-\sigma)\tilde{A}$ holds true or not, and thus whether the economy develops along a growth or a stagnation regime (see Proposition 2). We can observe that for low and high elasticity values the economy follows a stagnation regime along which the growth rate is zero, while for intermediate values it follows a growth regime along which the growth rate and elasticity relation is U-shaped.

Outside the parameter region in which the economy develops along a growth regime, the tax rate turns out to be too low or too high to start off an economic take off, consigning the economy to permanent stagnation. Along the growth regime, the growth rate is U-shaped related to the elasticity of the environmental damage. Thus, an increase in χ reduces output via damages, which in turn favors an increase in the tax rate to finance abatement. This generates a negative effect on disposable income which reduces capital accumulation and growth. A reduction in capital accumulation increases ρ and hence current consumption. However, beyond a certain value of τ, the benefits of abatement will show up increasing $\tilde{A}$, and hence capital accumulation and growth. Also, faster capital accumulation will make people more patient, further increasing growth via a reduction of ρ. These different effects imply that growth first decreases and then increases with the environmental damage elasticity.

The more inefficient the abatement technology (i.e., higher λ) the higher are pollution and damages, which slow down capital accumulation and growth. Intuitively, this is related to the fact that a higher degree of environmental inefficiency increases pollution, generating larger damages and thus slowing down capital accumulation and growth. Also, the more inefficient the capacity to abate, the higher the tax rate required for growth to pick up, explaining why the turning point of the growth rate shifts rightward when λ increases.

These results clearly show that the prospects of economic development at the national level may largely depend on the intensity of the environmental damages. Therefore, understanding the heterogeneous effects of climate change on national economic productivity is essential for international organizations to effectively plan and coordinate climate mitigation policies.

4 Conclusions

We analyze an endogenous growth framework in which production pollutes the environment and income taxation finances abatement activities, while the RTP negatively depends on the capital stock. Even if pollution does not affect utility or impatience, environmental parameters such as the elasticity of damages determine the optimal tax rate and thereby whether the economy stagnates or enjoys sustained growth. This suggests that cross-country heterogeneity in the environmental damages may explain the different development patterns followed by industrialized and developing economies.

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Technical Appendix [NOT FOR PUBLICATION]

By defining $\phi \equiv \int_0^t \rho_s ds$ and φ_i with $i = \{k, \rho\}$ the costate variables for capital and RTP respectively, the Hamiltonian function associated with the problem (1), (2) and (3) reads as follows:

$$\mathcal{H}(c_t, \tau_t, k_t, \rho_t) = \frac{c_t^{1-\sigma}}{1-\sigma} e^{-\phi} + \varphi_k \left[(1-\tau_t) \left(\frac{\tau_t}{\lambda} \right)^{\frac{\chi\omega}{1-\chi\omega}} A k_t - c_t \right] - \varphi_\rho \rho_t$$

First order necessary and sufficient (it is possible to prove that the Hamiltonian is concave) conditions turn out to be:

$$\begin{aligned}
& c_t^{-\sigma} e^{-\phi} = \varphi_k \\
& \varphi_k A k_t \left[\tau_t - \omega\chi \right] = 0 \\
& -\dot{\varphi}_k = \varphi_k (1-\tau_t) \left(\frac{\tau_t}{\lambda} \right)^{\frac{\chi\omega}{1-\chi\omega}} A - \varphi_\rho \rho_t' \\
& -\dot{\varphi}_\rho = -\frac{c_t^{1-\sigma}}{1-\sigma} e^{-\phi}
\end{aligned}$$

Straightforward algebra implies that $\tau_t^* = \tau^* = \omega\chi$ (see Proposition 1), while after some manipulations (see Strulik, 2012) the dynamics of the consumption to capital ratio $\psi_t = \frac{c_t}{k_t}$ and of the RTP can be written as in the following expressions:

$$\begin{aligned}
\frac{\dot{\psi}_t}{\psi_t} &= \frac{1-\sigma}{\sigma} \tilde{A} + \psi_t - \frac{\rho_t}{\sigma} + \frac{\eta}{\sigma} \left(\frac{\rho_t - \bar{\rho}}{\rho_t} \right) \left(\tilde{A} + \frac{\sigma}{1-\sigma} \psi_t \right) \\
\dot{\rho}_t &= -\eta (\rho_t - \bar{\rho}) \left(\tilde{A} - \psi_t \right)
\end{aligned}$$

where $\tilde{A} = (1-\tau^*) \left(\frac{\tau^*}{\lambda} \right)^{\frac{\chi\omega}{1-\chi\omega}} A > 0$. By setting the LHS of the previous equations equal to zero, we can obtain the two steady state equilibria given by $E_s = (\psi_s^*, \rho_s^*)$ and $E_g = (\psi_g^*, \rho_g^*)$, which are associated with the stagnation and growth regimes, respectively (see Proposition 2), and where $\psi_s^* = \tilde{A}$, $\rho_s^* = \frac{\tilde{A}+\Theta+\sqrt{(\tilde{A}+\Theta)^2-4\Theta\bar{\rho}}}{2}$, $\psi_g^* = \frac{\bar{\rho}-(1-\sigma)\tilde{A}}{\sigma}$, and $\rho_g^* = \bar{\rho}$, with $\Theta = \frac{\eta\tilde{A}}{1-\sigma}$. While equilibrium E_s exists and is well defined for all parameter values, equilibrium E_g does only whenever $\bar{\rho} > (1-\sigma)\tilde{A}$. Note that there exists another positive solution of the quadratic equation in ρ_t, but this is infeasible since it implies a value of the RTP lower than $\bar{\rho}$, which instead represents the minimal RTP associated with non-negative capital.

Linearization around the steady states show that E_s is locally unstable while E_g is saddle point stable, suggesting that whenever E_g exists in the long run the economy converges to the growth regime while when it does not the economy develops from time zero along the stagnation regime.