Quantifying distortions from pollution in a R&D endogenous growth model*

Cuantificación de las distorsiones atribuibles a polución en un modelo de crecimiento endógeno con I+D

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Abstract

In this note we study the distortions in an endogenous growth model developed by Grimaud and Tournemaine (2007), where new pieces of knowledge are produced in a R&D sector and used to reduce pollution emissions. Using this model along with a realistic calibration, we conclude that the economy strongly underinvests in R&D, such that the policy maker would need to implement a strong tax-subsidy scheme to correct it. We suggest that a subsidy to human capital can also decrease the gap between market and optimal allocations.

JEL Classification: *O13, O15, O31, O41, Q50.*

Key words: *Pollution, environmental tax, R&D, economic growth, subsidies.*

Resumen

Esta nota estudia las distorsiones en el modelo de crecimiento endógeno de Grimaud y Tournemaine (2007), en el que el conocimiento se genera en el sector de I+D y es usado para reducir la emisión de polución. Utilizando una calibración realista, concluimos que se subinvierte en I+D, lo que podría corregirse con un esquema fuerte de impuestos y subsidios. Sugerimos que un subsidio al capital humano podría reducir la brecha en las asignaciones de mercado y las óptimas.

Clasificación JEL: *O13, O15, O31, O41, Q50.*

Palabras clave: *Polución, impuesto ambiental, I+D, crecimiento, subsidios.*

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1. Introduction

This article quantifies the distortions present in the model of R&D endogenous growth with pollution, due to Grimaud and Tournemaine (2007). These authors presented an endogenous growth model with R&D and human capital accumulation to link environmental policy and economic growth and allocations, where knowledge-driven R&D activity results in technological knowledge used to reduce pollution emissions, and where pollution has a negative effect on welfare. This follows several articles beginning with Stokey (1998), which considers negative effects of pollution on utility and analyze pollution-related externalities and the related policies. Grimaud and Tournemaine (2007) present a quite innovative setup to study the interactions between environmental policy and growth in which human capital is considered a consumption good, firms compete *'a la Cournot'* and simultaneously perform R&D and sell the differentiated good. The authors conclude for an unusual effect of environmental tax on the economic growth rate. This effect, which is due to the view of human capital as a consumption good, has important policy implications.

When quantifying the effects of the distortions in the innovative model purposed by Grimaud and Tournemaine (2007), our paper must be seen as a note on theirs. Moreover, this note also contributes to a large literature on the optimality of investment in R&D (for a revision see Alvarez-Paleaz and Groth, 2005 and Reis and Sequeira, 2007). Quantification in R&D-driven endogenous growth models with natural resources or pollution has been rarely implemented in the specific literature, despite its importance. In fact, the precise policy implications from these models can only be complete through numerical exercises. We pursue this line in this article. The unique article that, to our knowledge, quantifies the R&D distortions present in an endogenous growth model with pollution is a recent one from Ferreira-Lopes *et al.* (2011), which used a model with different assumptions. Differently to what have been done in that article, this work focuses on the role of markups and technological externality, includes policy instruments such as taxes and subsidies. A unique feature of this model is that it internalizes several common distortions (such as spillovers, duplication effects, and creative destruction), and isolates the effect of markups and in particular of the technological distortion.

We provide a quantification of externalities in this endogenous growth model and show that the presence of a non-competitive market for differentiated goods and R&D together with a negative effect of pollution emissions on the consumers' utility lead the decentralized equilibrium solution to allocate fewer resources to R&D than the optimal solution, when considering reasonable values for the tax-subsidy scheme. For a reasonable calibration and with a moderate effect of technology in reducing emissions, the decentralized economy allocates less 20% of resources to R&D than the social planner would do. Increasing the effect of technology on pollution reduction would increase the underinvestment to near 40% less resources allocated by the market to the R&D sector.

The following section presents the model. Section 3 shows the main variables under social planner's framework and under the decentralized equilibrium. In section 4 we carefully calibrate the model and quantify the distortions. Section 5 presents an alternative policy to achieve the optimal solution. Section 6 concludes.

2. Model

For completeness, in this section, we briefly describe the model of Grimaud and Tournemaine (2007).

2.1. Production

Each quantity of the differentiated consumption good *j* (j = 1, …, N), produced in *j* exogenous sectors, by firm *qj* (*qj* = 1, ..., *Qj* identical firms), is achieved by using the technology: $Xqjt = AH_{qjt}^{x}$, where $A > 0$ is a production productivity parameter and H_{qjt}^{X} is the portion of human capital employed in the production of differentiated consumption good *j* by firm *qj*. Each firm also engages in R&D activities, which produces new knowledge, used to reduce pollution emissions. The accumulation of new knowledge assumes: $\dot{Z}_{qjt} = \delta H_{qjt}^{Z} Z_t^{\phi}$, where Z_{qjt} is the stock of knowledge of firm *q* operating in sector *j*, H_{qjt}^{Z} is human capital employed in research activities in firm *qj*, $Z_t = \sum_{j=1}^{N} \sum_{qj=1}^{Qj} Z_{qjt}$ is the aggregated stock of knowledge of the economy, $\delta > 0$ is a productivity parameter for research activities, and $0 < \phi < 1$ is a measure of spillover externalities.

New knowledge is employed in the reduction of pollution, which is caused by the productionof the differentiated consumption good. Each firm *qj* produces pollution emissions in the following way: $E_{qjt} = X_{qjt} Z_t^{-\beta}$ where $\beta > 0$.

2.2. Consumers

In this model population is constant and individuals are identical. Individuals accumulate human capital by going to school: $\dot{H}_t = \psi H_t^{H}$, where $\psi > 0$ is the productivity of the education sector and H^H is the portion of human capital dedicated to attending school. Consumers derive utility from the consumption of goods and a cleaner environment and also from human capital: $U = \int_0^{\infty} \left[\ln\left[\sum_{j=1}^{N} \left(c_{jt} \right)^{\alpha} \right] + \varepsilon lnH_t - \omega lnE_t \right] e^{-\rho} dt$, where $0 < \alpha < 1, \omega > 0$, c_{jt} is the *per capita* purchase of each differentiated consumption good *j*, $E_t = \sum_{j=1}^{N} \sum_{qj=1}^{Qj} E_{qjt}$ is the total flow of pollution emissions, ρ is the rate of time preferences (where $0 < \rho < \psi$), and ε is the effect of human capital in utility. There is no investment in this model, hence every differentiated consumption good *j* is consumed, such that $c_{jt} = X_{jt}$, where $X_{jt} = \sum_{qj=1}^{Qj} X_{qjt}$. Since it can be divided into skills for final good production (H^X), school attendance (H^H), and doing R&D (H^Z), and by assumption the different human capital activities are not done cumulatively, we have $H_t = H_t^H + H_t^X + H_t^Z$, where $H_t^X = \sum_{j=1}^{N} \sum_{qj=1}^{Qj} H_{qjt}^{X}$ and $H_t^Z = \sum_{j=1}^{N} \sum_{qj=1}^{Qj} H_{qjt}^{Z}$.

3. Allocations

3.1. Optimum

Given that at the optimum, the number of firms in each sector, Q, is given, the social planner problem is to maximize the utility function subject to the aggregated production function of good j $\left(X_{jt}=\sum_{qj=1}^{Qj}X_{qjt}=AH_{jt}^{x}\right)$, the aggregate production process of knowledge $\left(\dot{Z}_t=\sum_{j=1}^{N}\sum_{qj=1}^{Qj}\dot{Z}_{qjt}=\delta H_t^Z Z_t^{\phi}\right)$, the total flow of pollution emissions $\left(E_t=\sum_{j=1}^{N}\sum_{qj=1}^{Qj}E_{qjt}=\sum_{j=1}^{N}X_{jt}Z_t^{-\beta}\right)$ and the human capital static constraint. We refer to the Grimaud and Tournemaine (2007) article for the details of the social planner problem. From that problem we can obtain the following equations that relate the share of human capital in the human capital accumulation $\left(l^H=\dfrac{H_t^H}{H_t}\right)$ with the share of human capital in the differentiated goods sector $\left(l^X=\dfrac{H_t^X}{H_t}\right)$, and with the share of human capital allocated to the R&D sector $\left(l^Z=\dfrac{H_t^Z}{H_t}\right)$, which are presented in section A.2 of Grimaud and Tournemaine (2007):

(1) $$\psi l_*^H+\rho=\frac{\psi\beta\omega l_*^H}{(1-\omega)(1-\phi)}\,\frac{l_*^X}{l_*^Z},$$

and

(2) $$\psi l_*^H+\rho=\frac{\psi\varepsilon l_*^X}{(1-\omega)}+\psi.$$

These expressions and the human capital restriction $l^X=1-l^H-l^Z$ allows to obtain the shares of human capital.

3.2. Decentralized Equilibrium

In the decentralized equilibrium both consumers and firms have choices to make. Consumers maximize the intertemporal utility function subject to the human capital constraint and the budget constraint: $\dot{B}_t=rB_t+w_t\left(H_t-H_t^H\right)-\sum_{j=1}^{N}\left(1-\sigma_{jt}\right)p_{jt}c_{jt}+T_t$, where B_t is wealth, r_t is the interest rate, w_t is the wage rate, which we will set equal to 1, p_{jt} is the price of good j, σ_{jt} is the subsidy to the consumption of differentiated goods, and T_t is a lump-sum transfer. Note that, although pollution influences utility, there is nothing in the consumer choice affecting pollution directly, so that the consumer does not consider its evolution. This will be a source of externalities from the production to the consumption side.

Each firm *qj* produces and sells differentiated consumption goods on a non-competitive market (Cournot style, i.e., firms simultaneously choose their quantities without knowledge of the other firms' choices) and also knowledge. Let $\widetilde{\pi}_{qjt}$ be the profit of firm *qj* without payment of the knowledge $\left(V_t\,\dot{Z}_{qjt}\right)$. Hence, each firm maximizes profits $\widetilde{\pi}_{qjt} = p_{jt}X_{qjt} - \tau_t p_{jt}E_{qjt} - H^X_{qjt} + V_t\,Z_{qjt} - H^Z_{qjt}$. After making the necessary substitutions, the firm chooses X_{qjt}, H^Z_{qjt}, and the willingness to pay for new knowledge υ_{qjt}. The free-entry condition in the market for differentiated consumption goods implies that $\pi_{qjt} = \widetilde{\pi}_{qjt} - V_t\,\dot{Z}_{qjt} = 0$.

A symmetric equilibrium at steady-state is when there is a number of firms in each sector *j*, quantities and prices for each differentiated consumption goods are identical for all *qj* and for all *j* such that: $Q_j = Q$ for all *j*, $X_{qjt} = X_j / Q = X_t / Q, l^X_{qj} = \frac{l^X_j}{Q} = \frac{l^X}{NQ} =$, $l^Z_{qj} = \frac{l^Z_j}{Q} =$, $\frac{l^Z}{NQ}$, $Z_{qjt} = Z_{jt} / Q = Z_t / (NQ), E_{qjt} = E_{jt} / Q = E_t / (NQ)$, for all *qj* and for all *j*; $p_{jt} = p_t, \upsilon_{qjt} = \upsilon_{jt} / Q = \upsilon_t / (NQ), V_{qjt} = V_{jt} / Q = V_t / (NQ)$ for all *qj* and for all *j*. We refer to Grimaud and Tournemaine (2007) for details of the decentralized equilibrium problem.

The existence of a steady-state at the decentralized equilibrium requires that the term $\tau_t Z_t^{-\beta}$ is constant over-time. Hence, we assume that the government chooses a growth path for τ such that $g_\tau = \beta g_Z$ at any period in time, implying that $\tau_t Z_t^{-\beta} = \tau_0 Z_0^{-\beta}$ for all *t*, where τ_0 and Z_0 are respectively the initial values of τ_t and Z_t. From that problem, we can obtain the following equations, which are presented in section A.1 of Grimaud and Tournemaine (2007):

(3) $$\psi l^H_{de} + \rho = \frac{\psi\beta l^H_{de}\left(\tau_0 Z_0^{-\beta}\right)}{\left(1-\tau_0 Z_0^{-\beta}\right)(1-\phi)\left(1+(\alpha-1)Q\right)}\,\frac{l^X_{de}}{l^Z_{de}},$$

(4) $$\psi l^H_{de} + \rho = \frac{\psi\varepsilon(1-\sigma)\,l^H_{de}}{\left(1-\tau_0 Z_0^{-\beta}\right)\left(1+(\alpha-1)Q\right)} + \psi,$$

(5) $$l^X_{de} + l^Z_{de} = \frac{l^X_{de}}{\left(1+(\alpha-1)Q\right)}.$$

The shares of human capital allocated to the different sectors in the decentralized equilibrium, presented in Proposition 1 of Grimaud and Tournemaine (2007), are:

$$l_{de}^{H}=\frac{\psi\varepsilon(1-\sigma)+(\psi-\rho)\left(1-\tau_0 Z_0^{-\beta}\right)}{\psi\left(1-\tau_0 Z_0^{-\beta}\right)+\psi\varepsilon(1-\sigma)}\ , \tag{6}$$

$$l_{de}^{Z}=\frac{\beta\rho\left(\tau_0 Z_0^{-\beta}\right)}{(1-\phi)\left\{\psi\left(1-\tau_0 Z_0^{-\beta}\right)+\varepsilon(\psi+\rho)(1-\sigma)\right\}}\,l_{de}^{H}, \tag{7}$$

$$l_{de}^{X}=1-l_{de}^{H}-l_{de}^{Z}. \tag{8}$$

The differences between the social planner and the market solution are due to the effect of technologies on pollution, which is in fact the reason to have allocation of human capital to the R&D sector in this model.[1] Contrary to what is common in the endogenous growth literature, spillovers in R&D do not constitute a distortion in the economy. The reason is twofold: each firm uses its own R&D and internalizes its effect and R&D is not used to produce goods, it is only used to reduce pollution. These particular features of the model are useful to isolate the less studied effects of market power and of technological externality.

4. Quantitative Results

This section is the core of this note, implementing a quantitative evaluation of the distortions in the model. The calibration procedure performs a careful comparison between the parameters in the model and the available data.

4.1. Calibration procedure

Some of the parameters needed to calibrate this model have been used by previous articles. For the discount rate ρ we use a typical value of 0.02. For spillovers in R&D we use $\phi = 0.4$, which is more appropriate for models in which human capital accumulation is present, as empirical evidence suggest, an argument also followed by Reis and Sequeira (2007). In fact, recent empirical work that includes human capital, reveals lower values for national and international spillovers than the ones that have been reported before. According to results in Barrio-Castro *et al.* (2002), domestic spillovers in the presence of human capital decrease nearly 55% when compared to the model without human capital.

[1] For a complete comparison between allocations in the decentralized equilibrium and in the social planner solution, we need to acknowledge that the growth rates are equal in both solutions.

For ω we use the value presented in Stokey (1988) of 0.833. For the effect of human capital in utility (ε) and for the productivity of human capital allocated to attending school (ψ), we set it in order to obtain both a reasonable *per capita* growth rate of 1.85% (see e.g. Maddison, 2003) and a reasonable share of human capital in the human capital allocation sector. Gloom and Ravikumar (1998) estimated that this share can be as high as 60%, although considering that this is a generous estimation (Gloom and Ravikumar, 1998, p. 320). Jones *et al.* (1993, p. 500) indicates estimations for the share of time spent at school and on-the-job training on hours worked that oscillate between 37% and 42%. We assume an intermediate value of 50%. This implies $\psi = 0.0378$ and $\varepsilon = 0.0792$. For the fiscal instruments we assume a value of $\tau = 0.0285$,which is the average environmental taxes revenue as a share of GDP (data from 1997) (European Commission, 2001, Table 5). For the subsidy for the differentiated goods demand, we assume $\sigma = 0$. Usually, the subsidies to differentiated goods are given to the production of those goods. However, we may note that the value for the subsidy to physical capital costs is difficult to calculate, as was admitted by Devereux *et al.* (2002), since there are different forms of capital costs deductions. The investment tax credit of 10% had been abolished in the USA in 1986, although similar systems remain nowadays in countries such as the United Kingdom and Australia, where values range roughly between 30% and 50%, corresponding to values around 0.3. As Grossmann *et al.* (2010), we set this value equal to 0, as a benchmark exercise.

Finally, for the effect of technological progress on pollution, β, which is the focus of our study, we will perform considerable sensitivity analysis on it, always implying decreasing returns in influencing pollution, i.e. $0 < \beta < 1$.We summarize the parameters for the calibration exercise in Table 1.

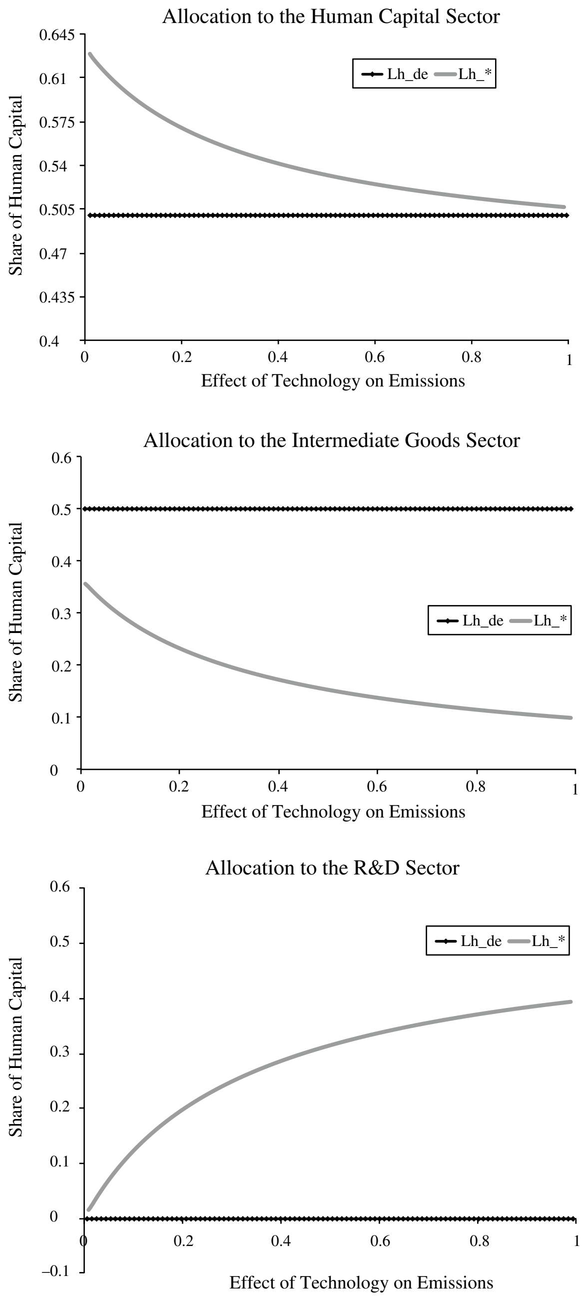
TABLE 1
CALIBRATION VALUES

Parameter	Basic Parameters
	Benchmark/Reasonable
ρ	0.02
ψ	0.037
ω	0.833
β	$0 < \beta < 1$
ε	0.0792
τ	0.0285
σ	0
g_Y	0.0185

4.2. Results

In this section, we present the results from our calibration exercise. The next figure presents the allocation of human capital throughout the three sectors in the economy (human capital, differentiated goods, and R&D), for different

FIGURE 1
HUMAN CAPITAL ALLOCATIONS TO THE DIFFERENT SECTORS
IN THE DECENTRALIZED EQUILIBRIUM AND IN THE
SOCIAL PLANNER SOLUTION



values of the effect of technology in decreasing emissions, the crucial effect on this paper. The decentralized equilibrium allocation to the human capital sector and to the differentiated goods sector is around 50% each, remaining nearly 0%, to the R&D sector. Although the first two are quite realistic values, the R&D share is quite low. As the parameters values that base our calibration were carefully chosen using international data or previous literature, this may be explained by the fact that the only use of R&D in this model is to reduce pollution. The optimal allocations of human capital to the differentiated goods sector begin near 35% (for low values of β) and decrease steadily to nearly 0.1%, while the allocation to R&D begin with a value near 0% and increase towards more than 35%. This pattern indicates a strong trade-off between the allocation of human capital to the human capital sector and the allocation to the R&D sector and in fact supports a heavy distortion towards decreasing pollution- R&D. The social planner would allocate up to 39% more human capital to develop new technologies that decrease pollution than the market does. Under the social planner solution, human capital allocated to the human capital sector does not oscillate a lot, decreasing from near 65% (when β is low) to near 50% (when β approaches 1).

We have performed a number of sensitivity analysis on the parameters that we now describe. Of particular interest are the parameters that could increase the share of human capital to the R&D sector to an interval of reasonable values. We tried to increase σ and we have concluded that for increases up to 50%, the value allocated to R&D does not increase significantly (with $\beta = 0.5$; $\sigma = 0 \Longrightarrow l_{de}^{Z} = 0.000574$; $\sigma = 0.5 \Longrightarrow l_{de}^{Z} = 0.000583$). The most significant change occurs with ω, which is the effect of pollution emissions in utility, internalized by the social planner. Reducing the value of ω would reduce the distortion, maintaining however the pattern shown in Figure 1 above. For $\omega = 0.4$, nearly half of the value used in Stokey (1998), the social planner would allocate up to 17% to the R&D sector, which compares with nearly 0% in the decentralized equilibrium. Due to the presence of markups in the economy it is even possible to obtain over investment in R&D. However, our quantitative exercise showed that this would occur for very low values of ω. In fact, maintaining the same calibration, with $\beta = 0.5$, we reach the conclusion that only with $\omega \leq 0.014$, is it possible to obtain overinvestment in R&D, i.e., a situation in which the optimal allocation to R&D is slightly below the market allocation to that sector.

5. Alternative Optimal Policy

The policies suggested by Grimaud and Tournemaine (2007) in Proposition 3 are not correct in order to obtain optimality in the decentralized equilibrium, as the tax on the pollution emissions provides incentives to perform R&D in order to reduce emissions, but the markup in the differentiated goods sector implies a lower allocation of human capital to the differentiated goods sector than the one that the social planner would provide. Comparing (1)-(2) and (3)-(5), Grimaud and Tournemaine (2012) have corrected the previously found policies[2].

We may note that alternatively, the government can implement the tax-policy as $\tau_t Z_t^{-\beta} = \omega$ suggested by Grimaud and Tournemaine (2007) in their Proposition 3, but a new policy is necessary: a subsidy to human capital allocation in the differentiated consumption goods sector. In this case the firm would only pay $(1 - s)$ of the wage, being the amount of the subsidy, s, paid by the government. This would change the firms' maximization problem and, in the end, with $s = (1 - \alpha)/Q$ this distortion would be eliminated[3]. Thus, a policy mix with a tax on pollution emissions $\tau_0 = \omega Z_0^{\beta}$ (with $g_\tau = \beta g_Z$ as mentioned above), a subsidy to the demand of differentiated goods (σ, as given above) and a subsidy to human capital employed in the differentiated consumption goods sector, $s = (1-\alpha)/Q = l^Z / \left(l^Z + l^X\right)$, would implement the optimal solution on this model. These policies would yield the equation:

$$(9) \qquad \psi l^H + \rho = \frac{\beta \tau_t Z_t^{-\beta} \psi l^H (1-s)}{(1-\phi)\left(1-\tau_t Z_t^{-\beta}\right)\left(1-\frac{1-\alpha}{Q}\right)} \frac{l^X}{l^Z},$$

equal to the optimal one (1) after substitution of the values of the policies.

This is an important conclusion as it means that the government may subsidize firms to hire human capital, implying that the policy mix may allow for the tax on pollution to fund (at least partially) the subsidy to human capital within firms and the subsidy to the differentiated goods' demand.

6. Conclusion

This note uses the model from Grimaud and Tournemaine (2007, 2012) to study the quantitative implications of such a theoretical environment. In this sense, this note complements their article in providing a quantification of the distortions in the model. We also add to the literature on optimal investments in R&D providing a reason behind the result of underinvestment in R&D: the fact that R&D decreases pollution.

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[2] We must note that for the decentralized economy to reach the optimum with the implementation of the so-called optimal policies, one is always assuming that the Government is fully aware of all the distortions and can quantify them. In fact, some kind of uncertainty about some of the components of the economy (preferences, technologies) may lead to worst outcomes than the decentralized economy ones. In order to guarantee that the purposed policies are welfare improving, independently of reaching or not the optimal solution, the welfare effect of different policies should be calculated.

[3] A complete proof for this claim is available upon request.

We implement a realistic calibration exercise, which shows that the model predicts strong underinvestment in R&D, such that the policy maker would need to implement a strong tax-subsidy scheme to correct it. In particular, our exercise predicts that governments should increase the environmental tax several times its current value. We suggest that a subsidy to human capital can also decrease the gap between market and optimal allocations.

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