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Optimal environmental policy in transport: unintended effects on consumers' generalized price[*]

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Abstract

Transport activity is strongly linked to environmental damage. However, transport operators may reduce their pollutant emissions through abatement effort. The government can make use of several instruments to increase the transport service operator's abatement effort, such as emissions taxes, emission subsidies or technological standards. All these instruments induce different effects on the number of operations to be offered and on the overall distortions of the economy. The optimal ranking of policies may strongly depend on whether regulators consider or not the effect that frequency has on consumers' generalized price. Thus, the main purpose of this paper is to highlight the importance of such an effect on regulation policies.

Keywords: environmental damage, generalized price, frequency

JEL Classification: Q53, H23, L91

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1   Introduction

The transport sector is quiet probably one of the most troublesome areas of the economy regarding production of externalities. Air quality, greenhouse gas emissions, noise, impact on biodiversity and land use are the main issues. About 90% of all lead emissions, about 50% of all nitrogen oxides (NOx) emissions and about 30% of all volatile organic compound (VOC) emissions, can be attributable to the transport sector (Hensher and Button, 2003).

Although most externalities found in transport have a negative impact, there may also be a positive one: the Mohring effect (Mohring, 1972). For buses, the Mohring effect relates to the reduction of passengers' waiting times at bus stops when the operator increases the frequency. Even though in other transport modes, such as air, rail and maritime transport, the arrival of vehicles to pick passengers up might not share the stochastic nature of buses, there exist effects of similar nature. Passengers have a preferred departure time and dislike the "schedule delay", which equals the difference between the actual and preferred departure time (see, for example, Brueckner, 2004, Panzar, 1979, or Pels and Verhoef, 2002). Increases in frequency reduce the "schedule delay" and, hence, consumers' generalized price.[1]

The treatment of externalities in transport is usually tackled at several grounds. We can mainly distinguish two types of policies:

1. Command and control measures concerning abatement. These are all measures intended to reduce the externality impact that are not market related. For example: restrictions on operations, restrictions on the type of technology and fuels used, the fulfilment of certain requirements and standards, etc.

2. Market related instruments. Any tax or subsidy aiming to reduce the externality level and hence the externality impact, forcing the operators to internalize the negative effects of their own actions.

Utilization of market related instruments for correction of externalities is less frequently found in reality. For the case of air transport the application of noise charges at airports is better known though still not widely applicable. Less well known and, hence much less frequent, are pollution related charges (Betancor and Martin, 2005). In general the options of reduction of noise at source and implementation of command and control instruments have been much more common in the regulatory practice. In the case of rail, road and maritime transport,

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[1]Additionally to the reduction in the "schedule delay", an increase in frequency may diminish consumers' generalised price since some indirect flights may be substituted by direct flights (Betancor and Nombela, 2002).

there is nothing like a noise or a pollution charge. Most measures concerning these modes have to do with the use of more environmentally efficient vehicles and fuels or with command and control measures. However the situation is starting to change. For instance in roads some types of vehicles (e.g. Four wheel drive) are being now subject to a special tax due to their higher pollution levels.

In roads revenues arising at the taxation of fuel may be seen as a way to pay for the externality, though this tax is not usually ear-marked in this regard. Other modes such as railways, maritime and air transport do not even pay taxes on fuel.

The existing literature on the treatment of externalities in transport usually concentrate its attention on solving just one externality, though there are some papers that consider the presence of multiple distortions (see, for example, Parry and Bento, 2002, or Verhoef, 2002). However, to our knowledge, regulation of negative externalities through any means and by taking into account its implications in terms of Mohring effects has not been considered till now.

In this work we analyze such an impact. We consider a route in which there is only a transport service provider. Each operation produces an environmental damage that may be reduced through an abatement effort made by carriers. Abatement effort is not costless, so it will not be exerted without public intervention. We concentrate our attention on three possible public instruments to increase the operators' abatement effort: an emission tax, an emission subsidy and a technological standard. Although these policies may be equivalent in order to achieve the socially optimal level of pollution, they have different effects on the frequency to be offered. However, such effects on the frequency are less severe if the Mohring effect is considered.

As it is usual in the literature, we assume that public funds are obtained through distortionary taxation. Emission taxes generate revenues that can be used to finance cuts in existing distortionary taxes. Some economists and politicians have argued that there might be a "double dividend" associated with the introduction of an emission tax: not only discourages environmentally damaging activities but also reduces the distortion cost of the tax system (see, for example, Goulder, 1995, Goulder *et al.*, 1997, Pearce, 1991, Poterba, 1993, or Repetto *et al.*, 1992).

In what follows we will show that the existence of a Mohring effect may have a crucial role when deciding the optimal environmental policy. Ignoring the importance of it may lead to the choice of wrong environmental policies, reducing the social welfare of the overall economy.

The rest of the paper is organized as follows. Section 2 presents the model. In section 3, we analyze as a benchmark situation the case in which there is not public intervention at all. For this case, we compare the private solution and the social optimum. In section 4, we discuss the

optimal environmental and importance of the Mohring effect. Section 5 concludes.

2 The model

We consider a route in which there is only a transport service provider with constant marginal operating cost denoted by c_o. The inverse demand function is assumed to be linear, this is:

$$G = \alpha - \beta Q, \tag{1}$$

where G denotes consumers' generalized price, α and β are positive parameters, and Q denotes the total number of operations or frequency. As Zhang and Zhang (2006) point out, this measurement of Q is equivalent to the number of passengers if each operation has an equal number of passengers, which holds when all vehicles are identical and have the same load factor.

Consumers' generalized price is the sum of the ticket price P and the value of the time spent in making the trip $vT(Q)$:

$$G = P + vT(Q), \tag{2}$$

where v is a positive parameter denoting the passengers' value of time, and $T(Q)$ is the total time that passengers spend in the trip (including the walking time to/from stops, the waiting time at stops and in vehicle time). The total amount of time required to make the trip decreases as the frequency increases, $\frac{dT(Q)}{dQ} < 0$. Thus, the higher the frequency, the lower consumers' generalized price. This effect is similar to the Mohring effect that is often considered in the context of the bus industry (Mohring, 1972).

In order to guarantee uniqueness of equilibrium for any possible value of the parameters β and v, we also assume that, for every strictly positive Q, the following condition for the function $T(Q)$ is satisfied:[2]

$$-2\frac{dT(Q)}{dQ} - Q\frac{d^2T(Q)}{dQ^2} < 0. \tag{3}$$

When operating, the transport provider produces pollutant emissions (e.g. noise and air pollution).[3] Each operation causes a constant environmental damage denoted by $d \in [0, 1]$. However, the operator may reduce the amount of his emissions of noise and air pollution through an abatement effort. Abatement effort can take different forms: the use of cleaner technology or cleaner fuels, lower speed, etc. Let us denote by $e \in [0, 1]$ firm's abatement effort per operation, which is supplied at a constant marginal cost c_e per operation. We assume quadratic costs for

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[2]There are several decreasing and convex functions for $T(Q)$ satisfying this expression. One example is $T(Q) = a + \frac{1}{Q^2}$.

[3]No other externalities inherent to the transport system such as congestion or accidents are considered.

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effort, $c_e = \frac{e^2}{2}$. This latter assumption implies that the marginal cost of abatement is rising, that is, more sophisticated and costly techniques are required to further decrease pollutant emissions.[4]

Thus, $(1 - e) \in [0, 1]$ denotes firm's final level of emissions per operation. We assume that if the transport service provider exerts an abatement effort e, then the environmental damage reduces to $d(1 - e)$.

From previous assumptions, we can deduce that the total cost of the transport operator $C(Q)$ is a linear function of the total number of operations. Formally:

$$C(Q) = c_T \ Q = (c_o + c_e)Q, \tag{4}$$

where c_T denotes the total marginal cost of the transport service provider, obtained as the sum of the marginal operating cost and the marginal cost of effort (both constant per operation).

3 Benchmark: No intervention

The operator chooses the level of frequency and abatement effort in order to solve the following maximization problem:

$$\underset{Q, \, e}{Max} \ \pi(Q, e) = [\alpha - \beta Q - vT(Q)]Q - c_T \ Q. \tag{5}$$

If the government does not intervene at all, the monopolist will choose the level of abatement effort that minimizes his total costs. Clearly, the operator's total costs are minimized by setting $e^{NI} = 0$, where the superscript NI denotes the case of no public intervention.

For the optimal choice of the frequency, the monopolist solves the maximization program given by expression (5). The choice of the operator is obtained by setting the first derivative of profits, $\pi(Q, e)$, with respect to Q equal to zero. Using subscripts to denote partial derivatives, the first order condition of such a maximization program can be written as:

$$\pi_Q(Q^{NI}, e^{NI}) = \alpha - 2\beta Q^{NI} - vT(Q^{NI}) - vQ^{NI}\frac{dT(Q^{NI})}{dQ} - c_T = 0. \tag{6}$$

The second order condition of the operator's maximization problem is given by:

$$\pi_{QQ}(Q^{NI}, e^{NI}) = -2\beta - 2v\frac{dT(Q^{NI})}{dQ} - vQ^{NI}\frac{d^2T(Q^{NI})}{dQ^2} < 0, \tag{7}$$

which, given our assumptions, it is clearly satisfied. Thus, expression (6) defines implicitly the optimal frequency to be offered by the transport service provider without public intervention.

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[4]The assumption of quadratic costs for abatement effort is usually applied in the environmental economics literature. Some examples are Calthrop and Proost (2003), Chavez and Stanlund (2003), Hoel and Karp (2001), Nannerup (1998), and Yates and Cronshaw (2001).

Let us compare the operator's optimal choice of abatement effort and frequency with the socially optimal solutions. Social welfare is defined as the sum of consumer surplus and the operator's profits, minus the external cost of environmental pollution. If the regulator were able to control directly the choice of abatement effort and frequency, he would solve the following maximization program:

$$\max_{Q,\,e} SW(Q,e) = \frac{1}{2}\beta Q^2 + [\alpha - \beta Q - vT(Q) - c_o - \frac{e^2}{2}]Q - d(1-e)Q. \tag{8}$$

First order conditions lead to the following expressions:[5]

$$e^{SO} = d. \tag{9}$$

$$\pi_Q(Q^{SO}, e^{SO}) + \beta Q^{SO} - d(1-e^{SO}) = 0, \tag{10}$$

where the superscript SO denotes the socially optimal solution. Investment in pollution abatement effort is optimal when the marginal cost of abatement per operation, e, equals the marginal benefit of abatement effort per operation, d. Hence, it is socially optimal to force the operator to exert a strictly positive effort in reducing noise and air pollution, though it is not socially optimal to force him to exert the maximum effort.

If the market size is high enough, the optimal frequency from the social point of view will be higher than the frequency offered by the monopolist. In this case, its socially optimal to increase the frequency since the social loss in terms of consumers surplus would be higher than the environmental damage. All these results are summarized in the following Lemma.

Lemma 1 *The socially optimal level of abatement effort per operation is higher than the effort exerted by the operator without pubic intervention. Moreover, if the market size is high enough, for every abatement effort, the socially optimal frequency is higher than the frequency offered by the operator.*

Proof. The socially optimal frequency is implicitly defined by expression (10). $\beta Q^{SO} - d(1 - e^{SO}) > 0$ if Q^{SO} is high enough, that is, if the market size is high enough. If $\beta Q^{SO} - d(1-e^{SO}) > 0$, then $\pi_Q(Q^{SO}, e^{SO}) < 0$. For a certain level of abatement effort e, the frequency Q offered by the operator is given by setting the first derivative of $\pi(Q,e)$ equal to zero: $\pi_Q(Q,e) = 0$. Since $\pi_{QQ} < 0$ for every strictly positive Q, $\pi_Q(Q^{SO}, e) < 0 = \pi_Q(Q,e)$ necessarily implies that $Q^{SO} > Q$, for every possible e. This completes the proof. ∎

From this simple case we can obtain some interesting results. Forcing the transport service provider to exert an strictly positive abatement effort would have a negative effect on frequency.

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[5] Given our asumptions, the social objective function is strictly concave, and hence the first order conditions are also sufficient.

However, the negative impact on frequency due to an increase in firm's abatement effort will be mitigated if the Mohring effect is considered. These results are formally stated in the following Proposition.

Proposition 1 *If the operator were forced to exert a strictly positive abatement effort, the optimal frequency to be offered would be reduced. However, such a reduction would be lower if the Mohring effect is considered.*

Proof. On the one hand, if the monopolist were forced to exert a strictly positive effort, his total marginal cost c_T would be increased. Applying the implicit function theorem to the first order condition given by expression (6), it is straight forward to prove that as c_T rises, the optimal frequency Q decreases. Formally:

$$dQ/dc_T = 1/\pi_{QQ} < 0,$$

where $\pi_{QQ} = -2\beta - 2v\frac{dT(Q)}{dQ} - vQ\frac{d^2T(Q)}{dQ^2}$ if the Mohring effect is considered, and $\pi_{QQ} = -2\beta$ otherwise. Since, for every strictly positive Q, $-2\frac{dT(Q)}{dQ} - Q\frac{d^2T(Q)}{dQ^2} < 0$, the reduction on frequency due to an increase in firm's abatement effort would be lower if the Mohring effect is considered. This completes the proof. ∎

The abatement effort is not costless so the transport operator will exert no effort without public intervention. Thus, in this context government's intervention is justified.

From Proposition 1 we can deduce that any policy aimed to increase the operator's abatement effort will have a negative impact on the frequency to be offered. However, such a negative effect will be mitigated if the Mohring effect is taken into account. The intuition of this result is as follows: If the total amount of time required to make the trip decreases with frequency, consumers' generalized price will decrease as frequency increases. So the higher the frequency, the higher the ticket price that the monopolist can charge to passengers. Therefore, when deciding the frequency to be offered, the monopolist takes into account the positive effects that frequency has on travel times.

The government can make use of several instruments to increase the transport service operator's abatement effort, such as emissions taxes, emission subsidies or technological standards. All these instruments induce different effects on the number of operations to be offered and the overall distortions of the economy. The optimal ranking of policies may strongly depend on whether regulators take or not into account the effect that frequency has on consumers' generalized price, that is, on whether the Mohring effect is or not considered.

4 Optimal environmental policy

A socially optimal level of pollution can be achieved by either an emission tax, an emission subsidy or a technological standard. Although these policies may be equivalent to achieve such an optimal level of pollution, they have different effects on the frequency to be offered by the monopolist, and thus on social welfare. Moreover, emission taxes generate revenues that can be used to finance cuts in existing distortionary taxes. Let us analyze the optimal environmental policy to be implemented.

In Section 3, we show that the social optimal level of abatement effort is $e^{SO} = d$. In this section, we will analyze three equivalent policies to implement such an abatement effort. The first one is an emission tax. Let t be the emission tax that the operator must pay per operation, which is proportional to his emission rate. The operator chooses the level of abatement effort in order to minimize his total costs. Thus, when deciding his abatement effort, the carrier must balance the additional cost of exerting more effort against the reduction in tax payments. Formally, the operator chooses the level of effort that solves the following minimization problem:

$$\underset{e}{Min}\ t(1-e) + \frac{e^2}{2}. \tag{11}$$

The first order condition requires that $e^{ET} = t$, where the superscript ET denotes the presence of an emission tax. Clearly, by setting $t = d$, the government implements the socially optimal effort. In this case, the carrier's total marginal cost is given by the following formula:

$$c_T^{ET} = c_o + d - \frac{d^2}{2}. \tag{12}$$

The second policy that might be used by the regulator to implement the socially optimal level of abatement effort is an emission subsidy. Let s be the emission subsidy per operation that the transport service provider obtains for each unit of abatement effort. In this case, when deciding the level of abatement effort to be exerted, the operator solves:

$$\underset{e}{Min}\ \frac{e^2}{2} - se \tag{13}$$

The optimal solution implies that $e^{ES} = s$, where the superscript ES denotes the presence of an emission subsidy. By setting $s = d$, the government implements the socially optimal effort, and the operator's total marginal cost is given by:

$$c_T^{ES} = c_o - \frac{d^2}{2}. \tag{14}$$

Finally, the third policy that might be used by the government to implement the socially optimal level of abatement effort is a command and control policy. Command and control regulations applied to transport typically imply the introduction of some requirements or standards

on the vehicles and the technology they use. Suppose that the regulator issues detailed requirements for the operator in order to force him to exert an effort $e^{TS} = d$, where the superscript TS denotes the presence of a technological standard. Then, the carrier's total marginal cost is given by the following expression:

$$c_T^{TS} = c_o + \frac{d^2}{2}. \tag{15}$$

Although the socially optimal level of abatement effort can be achieved either with an emission tax, an emission subsidy or a technological standard, these policies have different effects on the operator's total marginal cost and, thus, on the frequency to be offered. Indeed, comparing expressions (12), (14), (15), its straight forward to see that $c_T^{ES} < c_T^{TS} < c_T^{ET}$ and, thus, $Q^{ES} > Q^{TS} > Q^{ET}$. These results are summarized in the following Lemma.

Lemma 2 *The socially optimal level of abatement effort can be implemented either with an emission tax, an emission subsidy or a technological standard. However, these policies have different effects on the frequency to be offered by the monopolist. In particular, an emission subsidy induces the highest frequency while an emission tax the lowest.*

Proof. The frequency offered by the operator is given by setting $\pi_Q(Q, e^{SO}) = 0$. The optimal frequency Q is implicitly defined by such first derivative and $dQ/dc_T = 1/\pi_{QQ} < 0$. Since $c_T^{ES} < c_T^{TS} < c_T^{ET}$, then $Q^{ES} > Q^{TS} > Q^{ET}$, as we wanted to prove. ∎

With an emission subsidy the regulator manages to implement the socially optimal level of abatement effort and the highest frequency. But any subsidy requires the use of public funds that are obtained through distortionary taxation. Let λ denote the cost of public funds.[6] The social welfare if an emission subsidy is used to implement the socially optimal level of abatement effort $e^{SO} = d$ is given by the following formula:

$$
\begin{aligned}
SW(Q^{ES}, e^{SO}) &= \frac{1}{2}\beta(Q^{ES})^2 + [\alpha - \beta Q^{ES} - vT(Q^{ES}) - c_o + \frac{d^2}{2}]Q^{ES} - \\
&\quad - d(1-d)Q^{ES} - (1+\lambda)d^2 Q^{ES}.
\end{aligned}
$$

The socially optimal level of abatement effort may be also implemented through an emission tax, though this policy induces the lowest frequency. If we assume that the revenues that are obtained through such a tax are used to reduce the overall distortions of the economy, the social

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[6]There are several papers in the literature estimating the cost of public funds. For instance, Ballard, Shoven and Whalley (1985) find that the welfare loss due to 1% increase in all distortionary tax rates is between 17% and 56% per dollar. In the Canadian case, Campbell (1975) finds that this distortion is equal to 24%. More generally, it seems that the shadow cost of public funds falls in the range of 15% to 50% in contries with a developed efficient tax-collection system (Gagnepain e Ivaldi, 2002).

welfare is obtained by:

$$SW(Q^{ET}, e^{SO}) \quad = \quad \frac{1}{2}\beta(Q^{ET})^2 + [\alpha - \beta Q^{ET} - vT(Q^{ET}) - c_o - d + \frac{d^2}{2}]Q^{ET} -$$
$$-d(1-d)Q^{ET} + (1+\lambda)d(1-d)Q^{ET}.$$

Command and control policies can be implemented without affecting the government's revenues since they only imply the fulfilment of certain requirements. Thus, if a technological standard is used to implement the socially optimal level of abatement effort, the social welfare is given by the following expression:

$$SW(Q^{TS}, e^{SO}) = \frac{1}{2}\beta(Q^{TS})^2 + [\alpha - \beta Q^{TS} - vT(Q^{TS}) - c_o - d + \frac{d^2}{2}]Q^{TS} - d(1-d)Q^{ET}.$$

From Lemma 1 we know that, if the market size is high enough, the frequency offered by the operator is lower than the optimal frequency from the social point of view. Thus, if the market size is high enough, when deciding the optimal environmental policy to implement the socially optimal level of abatement effort, the regulator faces a trade off. On the one hand, the highest (lowest) frequency is obtained with an emission subsidy (tax). On the other hand, the use of subsidies increases (decreases) the overall distortion of the economy.

In this section we show that the optimal ranking of policies may vary if we consider the Mohring effect. If the regulator chooses an emission subsidy rather than an emission tax, we can deduce that the positive effect of subsidies on the frequency is higher than the negative impact of subsidies in terms of overall distortions on the economy. Since the effect on frequency is lower if there exists a Mohring effect, it may be the case that the optimal ranking of policies changes if the government does take into account this Mohring effect. This is stated in the following proposition.

Proposition 2 *The optimal ranking of policies may depend on whether regulators take or not into account the effect that frequency has on consumers' generalized price, that is, on whether the Mohring effect is or not considered.*

Proof. To demonstrate that this possibility can indeed arise, let us consider the following counter example. Assume that the total amount of time required to make the trip is given by $T(Q) = a + \frac{1}{Q^2}$, where a denotes the minimum time required to make the trip (access/ egress time plus travel time). As Q increases the total amount of time $T(Q)$ tends to the minimum a. This is the so-called Mohring effect.

When regulators do not take into account the Mohring effect, they consider that the total amount of time required to make the trip is given by: $T = a + b$, where b denotes the distance

between the real total time and the minimum. Such a distance is strictly positive and does not depend on the frequency. In other words, when regulators ignore the Mohring effect, they take the total travel time as given, disregarding the effects of frequency on such a total travel time.

Suppose the following values for the parameters: $\alpha = 70$, $\beta = 1$, $v = 6$, $a = 10$, $b = 0.4$, $c_o = 5$, $d = 0.5$, and $\lambda = 0.38$.

The following table compares the social welfare and the frequency offered by the operator if an emission subsidy, a technological standard or an emission tax is used to implement the socially optimal level of abatement effort, $e^{SO} = 0.5$, both in the case in which the Mohring effect is and is not considered. It also includes the frequency and social welfare obtained if there is no public intervention and the operator exerts no effort at all.

	The Mohring effect is not considered			The Mohring effect is considered		
	e	*Q*	*SW*	*e*	*Q*	*SW*
Emission subsidy	0.5	1. 3625	1. 9739	0.5	2. 9154	6. 8989
Technological standard	0.5	1. 2375	1. 9877	0.5	2. 8159	6. 9281
Emission tax	0.5	1. 1125	1. 9622	0.5	2. 7185	6. 9291
No intervention	0	1. 3	1. 885	0	2. 8654	6. 6951

Table 1: Comparison of environmental policies if the Mohring effect is and is not considered

If regulators do not take into account the Mohring effect, the optimal ranking of policies is, first, a technological standard, second, an emission subsidy and, third, an emission tax. However, if the Mohring effect is considered, the optimal ranking completely changes: first, an emission tax, second, a technological standard and, third, an emission subsidy. In both cases, for every environmental policy, the social welfare is higher than in the case in which there is no public intervention. Moreover, if we compare the frequency an level of social welfare for the cases in which the Mohring effect is and is not considered, we can observe that both are higher in the former case.

This completes the proof. ■

The Mohring effect may have a crucial role when deciding the optimal environmental policy. However, so far, the literature on environmental regulation has paid little attention to this fact. Ignoring the importance of the Mohring effect may lead to the choice of wrong environmental policies, reducing the social welfare of the overall economy.

5   Conclusions

The Mohring effect refers to the fact that, as the frequency increases, the total amount of time required to make a trip declines. Thus, as the frequency raises, consumers' generalized price decreases. Although this effect was firstly applied to the bus industry (Mohring, 1972), it can be extended to other transport modes, such as the rail, maritime or air transport.

The existence of a Mohring effect may have important consequences on the optimality of environmental policies. However, environmental regulators do not usually take into account the impact that the frequency has on consumers' generalized price. The model analyzed in this paper, though very simple, highlights the importance of the Mohring effect in optimal environmental and transport regulation. In particular, we show that if the Mohring effect is considered, the negative effect of environmental regulations on the frequency to be offered is mitigated. As a consequence, the optimal ranking of environmental policies may drastically change.

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