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Strategic environmental policies: Electric vehicles vs internal combustion engine vehicles

Políticas ambientales estratégica: vehículos eléctricos vs vehículos de combustión interna

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Abstract

In a world collapsed by pollution and environmental degradation, the decision of policies in favour of the environment is affected by the dilemma between economic efficiency and environmental protection. The objective of this article is to analyse this dilemma from the construction of a theoretical two-stage game model in which an environmental tax policy is chosen by government and local firms may produce differentiated vehicles: Electric Vehicles, Hybrid Vehicles, or Internal Combustion Engine Vehicles. At the first stage, the government determines the tax level on pollution taking the firms' output levels as given. At the second stage, firms, competing in an oligopolistic market, choose their output and emission levels observing the tax level set by the government. It is found that a high perception of pollution damage encourages the setting of a pollution tax despite the fall in the consumer surplus and the profits of Internal Combustion Engine Vehicles producers; this policy encourages the production of Electric Vehicles and Hybrid Vehicles. Otherwise, the government is not willing to set a severe pollution policy. This work is relevant because the level of environmental policy can be determined from the perception that people have about the environmental damage caused by the production of cars.

JEL Code: L13, H21, Q56
Keywords: strategic environmental policy; electric vehicles; pollution tax; pollution disutility; internal combustion engine vehicle

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Resumen

En un mundo colapsado por la contaminación y la degradación ambiental, la decisión de políticas a favor del medio ambiente se ve afectada por el dilema entre eficiencia económica y protección ambiental. El objetivo de este artículo es analizar este dilema a partir de la construcción de un modelo teórico de dos etapas en el que el gobierno establece un impuesto medioambiental, y las empresas locales pueden producir vehículos diferenciados: Vehículos Eléctricos, Vehículos Híbridos o Vehículos con Motor de Combustión Interna. En la primera etapa, el gobierno determina el nivel del impuesto sobre la contaminación tomando como dados los niveles de producción de las empresas. En la segunda etapa, las empresas, en un mercado oligopolístico, eligen sus niveles de producción y emisión observando el nivel de impuestos fijado por el gobierno. Se encuentra que una alta percepción de daños por contaminación incentiva la fijación de un impuesto por contaminación a pesar de la caída del excedente del consumidor y productor. De lo contrario, el gobierno no está dispuesto a establecer una política severa de contaminación. Este trabajo es relevante porque el nivel de política ambiental se puede determinar a partir de la percepción que tienen las personas sobre el daño ambiental que provoca la producción de automóviles.

Código JEL: L13, H21, Q56
Palabras clave: política ambiental estratégica; vehículos eléctricos; impuesto a la contaminación; desutilidad de la contaminación; vehículo con motor de combustión interna

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Introduction

The first-ever Global Sustainable Transport Outlook Report made by the United Nations (UN), addressing all modes of transport, in developing and developed countries defines sustainable transport as the provision of services and infrastructure for the mobility of people and goods - advancing economic and social development to benefit today's and future generations - in a manner that is safe, affordable, accessible, efficient, and resilient while minimizing carbon and other emissions and environmental impacts (UN 2016). Sustainable transport is also believed to be an essential ground to progress in realizing the promise of the 2030 Agenda for Sustainable Development and in achieving the 17 Sustainable Development Goals. Sustainable transport comprehends important emission reductions for fossil fuel vehicles (buses, trucks, and cars).

According to the International Energy Agency (IEA), globally, transport accounted for one-fourth of total emissions in 2016, 71% larger than in 1990. Road transportation takes the lead in the highest absolute. Overall, the share of road transport emissions increased by two percentage points to 74%, while air and water remained unchanged (IEA 2018a). That is, business, as usual, cannot be sustained for long. In fact, according to the World Health Organisation (WHO), nine out of ten people breathe polluted air, including from transport sources, and 7 million people die every year (WHO 2018).

These data encourage the use of new clean technologies such as those used by electric and hybrid vehicles. In fact, one of the ten recommendations by The High-Level Advisory Group on Sustainable Transport is to promote sustainable transport technologies through outcome-oriented government investment and policies that encourage private sector investment and action through various incentive structures (UN 2016). As nicely stated by Altenburg (2014), the negotiations between national governments and industries on low-carbon determine these policies and are closely tied to levels of environmental ambition, technological preferences (e.g., attitudes towards nuclear energy, shale gas, etc.), the degree of market imperfection, and on the expected co-benefits (e.g., green jobs or energy security).

Efforts to reduce the negative impact of pollution caused by gasoline vehicles depend on a set of public policies that foster the acquisition and use of electric and hybrid cars. To make this possible, public policy has to guarantee the benefit of companies, the disposition and purchasing capacity of the consumer, and the fiscal support of the government. Volkswagen (2019) argues that drivers who have been happily driving an Internal Combustion Engine Vehicle (ICEV) need more than just a little persuasion to give Electric Vehicle (EV) a chance. Even when it is perceived that the EV is an environmentally friendly transport option independently of the type (Ding et al. 2017), the EVs are not as desirable as expected as many restrictions appear on the market. The purchase of an electric or hybrid vehicle depends among many other reasons from consumers' attitudes formed by environmental concerns (Heyvaert et al. 2015, and Bennett 2015), and of consumer purchase capacity. The approaches to achieving this goal vary greatly from market to market: in regulatory, tax, and financial incentives – or a combination of all three. Public policies are highly required to create a profitable market for EVs and consumer requirements. Volkswagen (2019) shows a reasonable survey on the countries and policies used to promote electric vehicles.

According to ACEA (2023) the market share of electric cars expanded to 12.1% in 2022, an improvement of 3.0% compared to 2021. When it comes to hybrid and plug-in hybrid cars, they now register a share market share of 22.6% and 9.4%, respectively. By contrast, traditional gasoline and diesel fuels continued to lose ground. However, combined, they still accounted for more than half (52%) of European Union car sales in 2022.

However, the reality in some developing countries, and specifically in Latin America, is far from the functional optimism of European countries. Even though the market for electric and hybrid cars has grown significantly, this growth is very heterogeneous. Although in recent years the sales of electric vehicles have experienced significant growth in the world, in some developing economies this growth has not been as dynamic as expected. Although there are incentives for the entry of electric vehicles, the subsidy for fossil fuels in the Latin America region continues to be a factor to take into account, since economic activity in the region is based on the use of this dirty fuel. According to estimates by the

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International Monetary Fund (IMF 2021), in Latin America and the Caribbean 159,400 million dollars a in 2020 are paid in subsidies for fossil fuels.

Despite its accelerated increase, the segment of electric or hybrid cars is a minority in the countries of the Latin America region, for example, according to Statista (2022), in the Mexican and Chilean markets, these vehicles represent less than 10% of the total purchases of private cars in 2022. Among the reasons that hinder the adoption of electric vehicles in the Latin American market are the high price of the models, which are mostly imported. According to Briseño et al. (2021) in Mexico, for the buyers, the affordability of these vehicles is more important than their energy efficiency. It is a segment with relatively expensive costs. Other relevant reasons are the lack of clear and sounded financial incentives and, above all, the lack of an adequate charging infrastructure (Statista 2022). Thus, despite the enormous optimism about hybrid and electric cars, and the enthusiastic response in the global market. From the aforementioned, in some developing economies this growth in the sale of electric cars does not translate into a greater proportion of electric and hybrid cars in the vehicle fleet of many of the developing countries.

Our paper tailors such a model in which the government decides on public policies, (tax/subsidy), to be levied on vehicle industry producing differentiated vehicles, an EV at one extreme, or an ICEV at another extreme, or a Hybrid Vehicles (HV) in between the two extremes. The government's policy decision, which also affects the decision of the firms, basically depends on the price of the EV or HV (Zhang et al. 2016; Mersky et al. 2016; Boren and Ny 2016; and IEA 2018b), the income that the government could obtain from establishing a tax on gasoline cars production, and, relevantly, the perception about the disutility generated by the pollution generated by internal combustion cars. These three variables are important in low- and middle-income countries where the largest proportion of the population do not have access to an electric car. But in addition, the perception of the disutility generated by pollution implies a certain level of environmental awareness that in most developing countries is heterogeneous (Michel, P. & Rotillon, G. 1995; Espinosa Ramirez & Cruz Barba 2022).

Moreover, we do not intend to delve into the problem of the economic evaluation, or life cycle assessment of EVs, and on the comparison of EVs with ICEVs are growing as in Mersky et al. (2016); Holdway et al. (2010); Samaras and Meisterling (2008). Our focus is rather on the outcomes of the strategic actions of the governments and the producers in a context in which the prices of the cars differ according to the income of the people, and the perceived disutility of pollution emitted. How quickly to switch production from ICEVs to HVs and EVs is a central question, one that is driving divergent strategies. If automakers get ahead of consumers in introducing electric vehicles, that could inflate their costs and hurt sales of gas-powered vehicles, jeopardizing investment in EVs. Falling behind rivals in EV offerings, on the other hand, could cost them a chance to establish themselves in a key growth area for decades to come. This model, unlike the rest of the literature, tries to model this stylized fact in developing countries where environmental criteria and producers-government strategic interaction are different than in developed economies.

It is important to say that we follow the three principles set by Lundberg and Marklund (2018) in which (1) the policies should be effective, (2) there should be one objective per instrument, and (3) multiple objectives and multiple policy instruments must be mutually independent of each other. Our model setup covers almost all the aforementioned determinants in a game-theoretic framework which will be discussed in detail in the following sections.

Our starting assumption is that the EV sector has higher private costs and lower social costs. By implementing an encouraging public policy, governments may promote EV production and sales and create a stimulus to market creation and expansion. There are several measures to achieve these goals. For example, governments may promote public procurement programs for EVs, reduce the purchase price of EVs, reduce the costs for EV producers using subsidies, increase the costs for ICEV producers using tax regulations, reduce the operating costs for EV owners (e.g., discounted parking) and providing infrastructure or promoting the market for infrastructure investments. In this study, we propose a tax imposed on pollution because developing countries, generally, fiscal difficulties, and establishing taxes on the production of gasoline cars generates incentives for the adoption of clean technologies, and obtain tax revenues.

We assume as Fanti and Buccella (2017) the existence of a heterogeneous Cournot duopoly, and the use of a game-theoretic approach where the results are depending on the degree of product differentiation. We consider a model in which local firms produce differentiated goods. These firms compete in an oligopolistic market. The government chooses the level of public policy (tax) imposed on pollution to maximize welfare. The model is set on a two-stage game. At the first stage, the government determines the tax level on pollution taking the firms' output levels as given. In the second stage, firms choose their output and emission levels observing the tax level set by the government. As usual, the problem is solved using backward induction. Although Carbone et al. (2022) is an excellent reference on the management of environmental taxes to formulate some sub-optimal alternatives, we focus on a partial equilibrium model because we are interested in the strategic interaction between government and companies. The next section we point out the literature review. Next, we determine the basic economic model. After this, we carry out a comparative statics analysis. Posteriorly, the optimal policy is analysed. Finally, some concluding remarks are made.

Literature review

The strategic use of environmental policy instruments may be effective when production is the main source of pollution (Koska et al. 2021). The strategic role of production taxes as an instrument of environmental policy in the presence of disutility from environmental pollution, and the implications of the strategic use of this instrument on the production decisions of firms have not been studied sufficiently in recent literature, only Shao et al. (2019) develop a game-theoretic model to investigate what vehicle types should be produced from both private firms' and social perspectives (Shao et al. 2019). However, they focus on the consumer' decision rather than the strategic interaction between government and firms considering the consumer perspective. This is the main contribution of this article. In international trade models, Fujiwara (2012), Kayalica and Kayalica (2005), and Kayalica and Yilmaz (2006) analyze the relationship between import tariffs, export subsidies, and emissions taxes under consumption externalities (disutility), but they do not consider the strategic interaction between environmental policies and the production decisions of firms (Fujiwara 2012).

The literature has focused on the policies addressed to encourage the use of EVs as an alternative to reduce pollution. These policies are subsidies, tax incentives and financial incentives. For example, Gallagher and Muehlegger (2011) analyse the efficacy of fiscal and non-fiscal policies that induce consumer preferences of hybrid and EVs. Beresteanu and Li (2011) found that fuel price and income tax incentive programmes significantly affected the demand for HVs and EVs in the USA. Shepherd et al. (2012) examined the impact of subsidies, range, and emission rates on future EV demand. Huo et al. (2015) reviewed China's EVs subsidy scheme and estimated the impact on EV demand. Helveston et al. (2015) measured consumer preferences for EVs and examined the subsidy impact on EVs' purchasing. Bjerkan et al. (2016) identified that exemptions from purchase tax and VAT are important incentives for EV acquisition in Norway.

According to Moore II (2021), the environmental costs of producing and using ICEVs are real and significant but subsidizing the purchase and operation of electric vehicles very costly (mainly for some developing economies). Instead, tax internal combustion engines at a level that places the estimated cost of the environmental damage they do inside the price of such vehicles, and let the automotive market operate. The electric vehicle market will then thrive. This paper points out the use of a pollution tax in the context of the production and use of EVs, HVs and ICEVs. The question is, what is the optimal tax that a government could establish on the emission of pollutants due to the production of cars considering that its decision will affect the production decision of the companies and the consumer surplus? First, we are going to consider that the acquisition of an electric car by consumers depends entirely on the price. This is a sufficient explanation if we model this problem in the context of developing countries where charging stations together with limited range (He et al., 2013; Avci et al., 2015; Chen et al., 2016; Li et al., 2016; Liao et al., 2016), and consumer attitude (Larson et al., 2014; Bilotkach & Mills, 2012; Haustein & Jensen, 2018), are secondary variables.

Taxes on internal combustion vehicles have been a topic of interest in the literature on environmental and energy policy. One of the main reasons for these taxes is to address environmental externalities associated with vehicle use, including air pollution and greenhouse gas emissions. Taxes on internal combustion vehicles can be effective in reducing demand for such vehicles. Goulder and Parry (2008) found that a gas tax can reduce vehicle miles travelled significantly and reduce demand for new vehicles by up to 25%. Studies have shown that taxes on ICVs can be effective in reducing carbon emissions. Proost and Van Dender (2012) found that a 10% increase in the tax on gasoline could lead to a 5% reduction in carbon emissions in the United States. Similarly, a study by Stavins et al. (2007) found that a tax on ICVs could be more effective in reducing carbon emissions than other policy instruments, such as fuel economy standards. Schmalensee and Stavins (2017) discuss the use of cap-and-trade systems and taxes to reduce emissions from the transportation sector, including taxes on producers of internal combustion vehicles.

Even when the main objective of taxing ICEVs is to reduce or eliminate the environmental externality, this suggests that these taxes are a powerful tool to incentivize the purchase of electric vehicles. Towoju and Ishola (2020) argue for a tax on producers of these vehicles to reduce emissions and promote the development of cleaner technologies. Zhang et al. (2013) discuss the role of taxes and other incentives in promoting the adoption of electric vehicles, and the potential impact on producers of internal combustion vehicles. Yan (2018) models the potential impacts of a tax on producers of vehicles with low fuel economy and discusses the potential economic and environmental benefits. Even some taxing policies against ICEVs are directly related to encourage the adoption of EVs (Ji et al. 2022; Jenkins 2014).

On the other hand, there is also concern that such taxes may disproportionately affect low-income households, who may be more reliant on combustion vehicles for transportation as the cost of electric vehicles is prohibitive. Li et al. (2020) found that taxes on ICVs in China led to a significant reduction in sales of these vehicles and an increase in sales of electric vehicles. However, the study also found that the tax disproportionately impacted low-income households, who were less able to afford electric vehicles. Klier and Linn (2014) found that taxes on ICVs could lead to a reduction in consumer welfare, particularly for low-income households, who spend a higher proportion of their income on transportation.

One problem that arises with taxing ICEVs is the change in tax revenue. An increase in taxes on ICEVs initially increases tax revenue but can later lead to a reduction in tax revenue as EV adoption becomes more widespread. This dilemma is considered in this article, since although the government establishes a tax on the production of ICEVs, the companies decide on the type of cars to produce according to the fiscal and production costs.

This problem of falling tax revenue is more relevant in developing countries, and specifically in Latin American economies. For example, in the case of Mexico, in Bonilla et al. (2022), in a scenario up to 2050, they predict a drop in income of 21.6% per year with the adoption of EVs. On the other hand, in the case of Ecuador, Bedoya Jara, et al. (2017) based on a basic principle of environmental taxation: whoever pollutes, pays, the collection effect, has allowed the Government to implement important environmental measures. In the case of Chile, Martinez (2020) makes a careful analysis of the use of green taxes where the amount and efficiency must be taken care of when implementing these taxes, because exceeding them could break the tax balance.

In short, despite the growing optimism in the adoption of EVS in developed countries, in developing countries, and especially in Latin American countries, this optimism is relative. The cost of EVs, the fiscal limitations in the adoption of tax schemes, and the impact of these policies on the welfare of both the consumer and the producer, make the rates of adoption in these economies slower (Rajper & Albrecht, 2020; Adhikari et al., 2020). Establishing a tax on the production of ICEVs by the government implies, in many of the Latin American economies, considering not only the environmental impact, but also the benefit of consumers who face high prices for EVs, and the benefit of producers and how they interact with these tax policies adapting their productive transition from ICEVs to EVs. In this paper, we develop a theoretical model of this stylized fact that has not been considered in recent literature.

Model framework

We use the simplest possible structure capable of bringing out the main points. In this model, there are two firms a and b, both firms produce a differentiated good in terms of cost and demands. The firm a produces ICEVs, and firm b may produce ICEVs, HVs, or EVs. The election of firm b is going to depend on the cost structure. On the other hand, we assume linear demands as in which we have quasilinear preference under a numeraire commodity. This assumption is convenient as the vehicle demanded (as a good) is strictly different from other goods in which the income effect is highly related. When we use general preferences the results of the model are the same but more complicated in terms of mathematical expressions. We use linear demands for simplicity because another kind of demands do not change the conclusions of the paper. The linear demands are

$$p_a = 1 - D_a \tag{1}$$

$$p_b = 1 - D_b \tag{2}$$

where p_a and p_b are the prices of goods produced by firms a and b such that

$$D_a = x_a + \gamma x_b \tag{3}$$

$$D_b = x_b + \gamma x_a \tag{4}$$

D_a and D_b stand for the demands of goods a and b. x_a is the ICEVs produced by the firm a, x_b are the vehicles produced by firm b, and γ is the degree of differentiation such that $1 \geq \gamma \geq 0$. When $\gamma = 1$ both goods are perfectly homogenous and are ICEVs, and we have only one demand function, and when $\gamma = 0$ both goods are totally differentiated, and firms produce ICEVs and EVs. However, when we have a value between zero and one it means we have a kind of HVs produced by firm b. These HVs may have a different degree of environmental cleanness according to the level of differentiation. The firms are defined as

$$\pi_a = (p_a - k_a)x_a \tag{5}$$

$$\pi_b = (p_b - k_b)x_b \tag{6}$$

where π_a and π_b denote the profits of firms a and b. Firms compete in an oligopolistic setting where k_i is the constant marginal (and hence, average cost) such that $(i = a, b)$. The firms are assumed to behave in a Cournot-Nash fashion. Hence, profit maximization yields first-order conditions of (5) and (6) as

$$1 - 2x_a - \gamma x_b - k_a = 0 \tag{7}$$

$$1 - 2x_b - \gamma x_a - k_b = 0 \tag{8}$$

It can easily be verified that with the linearity of demand the second-order conditions are always satisfied. Solving (7) and (8) we have profit-maximizing equilibrium output for both types of firms;

$$x_a = \frac{2(1-k_a) - \gamma(1-k_b)}{(4-\gamma^2)} \tag{9}$$

$$x_b = \frac{2(1-k_b) - \gamma(1-k_a)}{(4-\gamma^2)} \tag{10}$$

Substituting (10) and (9) into (7) and (8) we find the optimal profits as

$$\pi_a = x_a^2 \tag{11}$$

$$\pi_b = x_b^2 \tag{12}$$

We consider that the firms are differentiated by the environmental technology adopted by firm b. While firm a produces ICEVs, firm b may produce EVs or HVs. In other words, when $\gamma = 1$ both goods are homogenous and both firms produce ICEVs, and when $\gamma = 0$ both goods are totally differentiated and the firm b produces EVs and firm a produces ICEVs. Something in between ($1 > \gamma > 0$) means that firm b produces HVs. However, this model setting is straightforward and flexible enough to implement for more general cases in different industries. The cost to produce an ecologically better vehicle implies adopting a more expensive technology. The structures of cost in both firms are

$$k_a = c_a + \lambda\theta_a \tag{13}$$

$$k_b = c_b(\gamma) + \lambda\theta_b(\gamma) \tag{14}$$

The unit cost of production, k_i the first term in (13) and (14) is c_i, which is the part of the unit cost that is determined by technological and factor-market conditions, and it is taken to be constant. However, this cost in the firm b is determined by the degree of differentiation $c_b = c_b(\gamma)$, such that $c_b^H \geq c_b \geq c_a$, where $c_b(0) = c_b^H$, and $c_b(1) = c_a$. Adopting a clean environmental strategy is more expensive than adopting the normal strategy of producing ICEVs.

On the other hand, the amount of pollution generated (before any abatement) by each firm is $\theta_i x_i$, where θ_i is the amount of pollution per output emitted by production process and it is constant. A small θ_i means that the environmental production technology adopted by a firm is more efficient, there is less pollution emitted by the firm. However, this technology in firm b depends on the degree of differentiation as well. In this case, this technology would be the same if both goods are homogenous such that $\theta_b(1) = \theta_a$, but with completely differentiated goods, the technology of production is less polluting in firm b than in firm a such that $\theta_b(0) = 0$. So, we have $\theta_a \geq \theta_b \geq 0$. We assume that the abatement technology is such that it costs each firm a constant amount λ to abate one unit of pollution. From (13) and (14) we have

$$k_b - k_a = c_b - c_a + \lambda(\theta_b - \theta_a) \geq 0$$

It is clear that the unit cost of firm b is larger than the unit cost of firm a. Adopting environmental technology is more expensive than normal non-environmental technology. From here we can deduce that

$$x_a - x_b = \frac{(2+\gamma)(k_b - k_a)}{(4-\gamma^2)} > 0$$

With no pollution policy, and given the cost difference, the goods produced by the firm a is larger than firm b. In other words, the vehicles produced by the firm a are larger than firm b. Finally, from (11) to (14) we get

$$\pi_a - \pi_b = \frac{[(1-k_a)^2 - (1-k_b)^2]}{(4-\gamma^2)}$$

Clearly, we have that $\pi_a - \pi_b \geq 0$.

Here, we wonder how pollution may affect the health of the people in the country given by environmental degradation. Pollution here is considered a negative externality which implies some cost to abate it. This negative externality calls for a policy effort to reduce the emission of pollution. For this to be the case, we assume a government that is considering applying an environmental policy, let say tax, to control the emission of pollution to avoid environmental degradation. Following Lahiri and Ono (2000), we consider a pollution tax, which may affect the car production decision, and therefore, the amount of pollution emitted into the atmosphere. The cost structure would be rewritten from (13) and (14) as

$$k_a = c_a + \lambda(\theta_a - z_a) + tz_a \tag{15}$$

$$k_b = c_b(\gamma) + \lambda(\theta_b(\gamma) - z_b) + tz_b \tag{16}$$

A part of k_i, the first term, is given by technological and factor market conditions, and the remaining parts are policy-induced. A pollution tax has two associated costs to the firms: (i) the tax paid, and (ii) the cost of pollution abatement. Denoting z_i the post-abatement pollution level per unit of output, $\lambda(\theta_i - z_i)$ is the unit abatement cost, and tz_i the unit tax paid.

To set an optimal policy, the government is willing to set a pollution policy taking into account the benefit on the health of the people and tax revenue, and the reduction in consumer and producer surplus given by the increase in production costs. The government maximizes a welfare function like:

$$W = \pi_a + \pi_b + CS + tR - \psi R \tag{17}$$

where the first two terms are the producer surpluses, the third term is the consumer surplus, the fourth term is the tax revenue, where t is the pollution tax, and the fifth term is the pollution disutility where ψ is the marginal pollution disutility, and R is the amount of pollution emitted into the atmosphere. The consumer surplus is defined as $CS = CS_a + CS_b$ such that from (1) and (2) we get

$$CS_a = \frac{D_a}{2} \tag{18}$$

$$CS_b = \frac{D_b}{2} \tag{19}$$

The total amount of pollution is defined as

$$R = z_a x_a + z_b x_b \tag{20}$$

Once we have set the basic framework of the model, we determine some comparative statics to determine the optimal pollution tax t^*. The model is set on a two-stage game. At the first stage, the government determines the tax level on pollution taking the firms' output levels as given. In the second stage, firms choose their output and emission levels observing the tax level set by the government. As usual, the problem is solved using backward induction. With these equations and game-theoretic structure, we complete the model specification and turn to its analysis in the following sections.

Comparative statics

The setting of a pollution tax affects primarily the cost of firms. It is clear to say that any tax is affecting negatively the cost structure of firms. From (15) and (16) we have

$$\frac{dk_i}{dt} = z_i > 0 \tag{21}$$

An increase in pollution tax increases the cost of firms. By (21) we consider that the impact of tax on costs affects the optimal output or the number of vehicles produced. From (9) and (10) we have

$$\frac{dx_a}{dt} = \frac{[\gamma z_b - 2z_a]}{(4-\gamma^2)} \tag{22}$$

$$\frac{dx_b}{dt} = \frac{[\gamma z_a - 2z_b]}{(4-\gamma^2)} \tag{23}$$

The impact of a pollution tax on the optimal output depends on the degree of differentiation. When $\gamma = 1$ the result seems to be negative because the amount of pollution emitted by the two firms would be the same, and therefore an increase in the pollution tax reduces the output of the firms. When both goods are completely differentiated ($\gamma = 0$) an increase in pollution tax reduces the ICEVs produced. From (11) and (12) we have

$$\frac{d\pi_a}{dt} = 2x_a \frac{[\gamma z_b - 2z_a]}{(4-\gamma^2)} \tag{24}$$

$$\frac{d\pi_b}{dt} = 2x_b \frac{[\gamma z_a - 2z_b]}{(4-\gamma^2)} \tag{25}$$

The intuition is similar to the previous case. When γ=1 the result seems to be negative because, presumably, since they are homogeneous goods, the amount of pollution emitted by the two firms would be the same, and therefore an increase in the pollution tax reduces the profit of the firms. When both firms are completely differentiated, a pollution tax reduce the profits of firm producing ICEVs. To obtain the comparative static of consumer surplus, we have from (16) and (17)

$$\frac{dCS_a}{dt} = \frac{D_a}{(4-\gamma^2)}[z_a(\gamma^2-2) - \gamma z_b] < 0 \tag{26}$$

$$\frac{dCS_b}{dt} = \frac{D_b}{(4-\gamma^2)}[z_b(\gamma^2-2) - \gamma z_a] < 0 \tag{27}$$

Independently of the level of differentiation, the consumer surplus is reduced with an increase in pollution tax, although with fully differentiated goods the consumer surplus of electric cars does not change. The impact of a pollution tax on tax revenue is given by

$$\frac{d(tR)}{dt} = \frac{2t}{(4-\gamma^2)}[\gamma z_a z_b - z_a^2 - z_b^2] + R \tag{28}$$

There is a positive impact given by the increase in pollution tax, and a negative impact given by the impact of a pollution tax on the optimal outputs. An increase in the pollution tax means more income for government, but this tax discourages the production of polluting goods. Independently of the degree of differentiation, the overall effect seems to be ambiguous. When both goods are completely homogenous, the amount of tax collected, and the reduction in the optimal output are the largest possible. With completely differentiated goods the amount of tax collected and the reduction in the output are the smallest one. Finally, the impact of a pollution tax on people's health is given by

$$\frac{d(\psi R)}{dt} = -\frac{2\psi}{(4-\gamma^2)}[\gamma z_a z_b - z_a^2 - z_b^2] > 0 \tag{29}$$

There is positive impact of a tax on pollution disutility given reduction of pollution given by the production process independently of the degree of differentiation. It is defined by the reduction in the output, and it is larger as more homogeneous are the goods.

Optimal pollution tax

Once we have set some comparative statics, we derive the optimal. Derivation of (17) respect to the optimal pollution tax, and considering (21) to (29) we get

$$\frac{dW}{dt} = 2x_a \frac{[\gamma z_b - 2z_a]}{(4-\gamma^2)} + 2x_b \frac{[\gamma z_a - 2z_b]}{(4-\gamma^2)} + \frac{D_a}{(4-\gamma^2)}[z_a(\gamma^2-2) - \gamma z_b] + \frac{D_b}{(4-\gamma^2)}[z_b(\gamma^2-2) - \gamma z_a] + \frac{t-\psi}{(4-\gamma^2)}[2\gamma z_a z_b - 2z_a^2 - 2z_b^2] + R = 0 \tag{30}$$

The result seems ambiguous, and we need to consider some restrictions. According to (15) and (16), the firms decide on z_i and x_i. The firms' optimal behaviors on pollution emission give

$$z_i = \begin{cases} 0 \ if \ t \geq \lambda \\ \theta_i \ if \ t < \lambda \end{cases} \tag{31}$$

As Lahiri and Ono (2000) argue, the firms do not abate pollution at all when the tax rate is smaller than the private marginal cost of abatement; they simply prefer to pay the tax. On the other hand, when the tax rate is larger than the marginal cost of abatement, the firms emit only the harmless level of pollution. Substituting (31) into (15) and (16) we have

$$k_i = \begin{cases} c_i + \lambda\theta_i \ if \ t \geq \lambda \\ c_i + t\theta_i \ if \ t < \lambda \end{cases} \tag{32}$$

and from the total amount of pollution (20) we have

$$R = \begin{cases} 0 \ if \ t \geq \lambda \\ \theta_a x_a + \theta_b x_b \ if \ t < \lambda \end{cases} \tag{33}$$

From (33), when $t \geq \lambda$, the amount of pollution is zero independently of the pollution tax. When $t < \lambda$, all firms pay the pollution tax as none of them abates any pollution. Since the first case, no pollution is emitted independently of pollution tax; we focus on the second case in order to determine how the differentiation level affects the optimal pollution tax. Considering this case, and given that $\theta_a \geq \theta_b \geq 0$, we substitute (31) in the comparative statics from (22) to (25), and (29), we have the following intuition,

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$$\frac{dx_a}{dt} = \frac{[\gamma\theta_b - 2\theta_a]}{(4-\gamma^2)} < 0 \tag{34}$$

$$\frac{dx_b}{dt} = \frac{[\gamma\theta_a - 2\theta_b]}{(4-\gamma^2)} \tag{35}$$

$$\frac{d\pi_a}{dt} = 2x_a\frac{[\gamma\theta_b - 2\theta_a]}{(4-\gamma^2)} < 0 \tag{36}$$

$$\frac{d\pi_b}{dt} = 2x_b\frac{[\gamma\theta_a - 2\theta_b]}{(4-\gamma^2)} \tag{37}$$

$$\frac{d(\psi R)}{dt} = \frac{\psi}{(4-\gamma^2)}[2\gamma\theta_a\theta_b - 2\theta_a^2 - 2\theta_b^2] < 0 \tag{38}$$

From (34) to (37), we have that an increase in pollution tax reduces the output and the profit of firm a, independently of the degree of differentiation. In other words, pollution tax decreases the production of ICEVs. On the other hand, the impact of a pollution tax on output and profit of the firm b depends on the degree of differentiation: with a larger degree of differentiation, the increase in the pollution tax increases the output and profit of firm b. It means, more EVs or HVs are produced. With a small degree of differentiation, the opposite intuition holds.

From (38) we have that an increase in pollution tax reduces the pollution disutility on people's health. It is because there is a reduction in the total pollution emitted into the atmosphere. The impact of a pollution tax on consumer surplus and tax revenue is the same as described above. To obtain the optimal policy, we rewrite (30) as

$$\begin{gathered}\left.\frac{dW}{dt}\right|_{t<\lambda} = 2x_a\frac{[\gamma\theta_b - 2\theta_a]}{(4-\gamma^2)} + 2x_b\frac{[\gamma\theta_a - 2\theta_b]}{(4-\gamma^2)} + \\ \frac{D_a}{(4-\gamma^2)}[\theta_a(\gamma^2-2) - \gamma\theta_b] + \frac{D_b}{(4-\gamma^2)}[\theta_b(\gamma^2-2) - \gamma\theta_a] \\ + \frac{2(t-\psi)}{(4-\gamma^2)}[\gamma\theta_a\theta_b - \theta_a^2 - \theta_b^2] + R = 0\end{gathered} \tag{39}$$

The next step is to determine the optimal pollution tax, which is easier considering that $\theta_a \geq \theta_b \geq 0$. From (39), and providing the second-order condition hold, we can get the optimal tax as:

$$t^* = \psi - \frac{1}{2A_1}[\theta_a A_2 + \theta_b A_3] \tag{40}$$

where

$$A_1 = \gamma\theta_a\theta_b - \theta_a^2 - \theta_b^2 < 0$$
$$A_2 = \gamma x_b(\gamma^2 - 1) - x_a(\gamma^2 + 2) < 0$$
$$A_3 = \gamma x_a(\gamma^2 - 1) - x_b(\gamma^2 + 2) < 0$$

The optimal tax depends on the marginal pollution disutility such that a sufficiently larger marginal pollution disutility promotes the setting of a pollution tax ($t^* > 0$). Intuitively, the government is willing to set a strict pollution policy because the reduction in the harmfulness of pollution on people's health is larger than the loss in consumer and producer surplus given by the increase in costs. A sufficiently small marginal pollution disutility promotes the setting of no pollution policy ($t^* = 0$). The government is not considering the people's health. Both results are independent of the degree of differentiation.

If we consider the optimal tax under different scenarios of differentiation, we have remarkable results. We take the extreme cases in which there is total differentiation or no differentiation at all ($\gamma = 0$ and $\gamma = 1$). Evaluating (40) in the case in which we have complete differentiation, such that that $\gamma = 0$, $\theta_b = 0$ and $x_b < x_a$, we have

$$t^*\Big|_{\gamma = 0} = \psi - \frac{x_a}{\theta_a} \tag{41}$$

In the case in which we have complete homogenous goods, we consider, as the assumptions made above, that $\gamma = 1$, $\theta_b = \theta_a$ and $x_b = x_a$. Evaluating (40) in the case of perfectly homogeneous goods we have

$$t^*\Big|_{\gamma = 1} = \psi - \frac{6x_a}{\theta_a} \tag{42}$$

Taking the difference between (41) and (42) we have that

$$t^*\Big|_{\gamma=0} - t^*\Big|_{\gamma=1} = \frac{5x_a}{\theta_a} > 0 \tag{43}$$

The optimal tax set by the government in the case in which we have complete differentiation is larger than the tax set in the case in which we have complete homogenous goods. From here, and considering the linearity of the tax, we can deduce that a reduction in the level of differentiation (an increase in γ) reduces the optimal tax. It means,

$$\frac{\mathrm{d}t^*}{\mathrm{d}\gamma} < 0$$

This result holds once the tax is positive, it means with a sufficiently large pollution disutility. In the case in which the marginal pollution disutility is small, and the tax is zero, an increase in the degree of differentiation does not affect this policy unless a subsidy to pollution is considered. In this case both firms produce ICEVs as the cost of production is smaller than producing HVs or EVs according to (24) and (25).

It is a surprising result in many aspects. Taking the case in which the marginal pollution disutility is large, a reduction in the level of differentiation (both firms produce polluting vehicles as ICEVs and HVs) means that the environmentally friendly firm becomes more polluting. Given the large marginal pollution disutility, it is expected to have a large pollution tax. However, it is not the case, and, with a small degree of differentiation (more homogeneous firms), the pollution tax is reduced because the consumer and producer surplus become relevant in the policy decision.

In the case in which we have total differentiation, the producer surplus of the environmentally friendly firm b for producing EVs, and the benefit in consumption given by this firm, compensate the loss in producer surplus of the firm a for producing ICEVs, and the loss in consumption of ICEVs. With complete homogenous firms producing ICEVs, the impact of a tax on consumer and producer surplus is larger than in the case of complete differentiated goods where firm a produces ICEVs and firm b produces EVs, so the government set a smaller pollution tax.

In our case, when firm b decides to produce a vehicle closer to the ICEVs rather than EVs, the tax levy by the government is reduced because the consumer will face higher prices given by the tax to the polluting vehicles and the consumer surplus becomes important in the policy decision of the government. Reducing pollution tax to vehicle producers reduces the cost of producing, and therefore the price for consumers despite the pollution disutility. When both producers get closer in producing polluting cars (or ICEVs) discourage the pollution policy.

Conclusions

Globally speaking transport is responsible for one -fourth of total emissions in 2016, while road transportation alone takes the lead with a share of 74%. This means road transportation alone is responsible for almost 19% of the overall air pollution in the world. EVs, if in particular tied to renewable energy grids, would help significantly to mitigate climate change. To encourage the industry and hence boost EVs production public policies must be implemented in an increasing fashion. However, this decision should consider the loss in consumer and producer surplus given by the reduction in the ICEVs.

Despite the optimism in the growth of the EV market in developed countries, the scenario in developing countries is not so encouraging. The growth in the electric car market is not high, and the reason for this slowdown comes from the reluctance to implement more aggressive policies against the use of ICEVs due to various reasons. First, the cost of these cars in the market is high compared to the low income of the majority of the population, discouraging the consumption of ICEVs in favour of EVs affects consumer surplus. Second, the drop in ICEV production affects producer surplus. Third, the perception of environmental damage in developing countries is limited.

Promoting EVs reduce the benefit offered by the ICEVs industry and, in developing economies, it seems to be crucial. In developing economies, there is an interaction between the government policy aimed at promoting the use of EVs through taxes on ICEVs (tax collection is more profitable than subsidizing EVs), and the strategies of car manufacturers on their production decision of EVs and ICEVs. In this article, this stylized fact is modelled where the interaction between companies and government is analysed in the face of the dilemma of encouraging the use of EVs by imposing environmental taxes on the production of ICEVs. This stylized fact, very consistent with the reality of developing countries in general, and of Latin American economies in particular, is analysed using a game-theoretic framework. This stylized fact has not been analysed in the literature so far and makes this work relevant in theoretical terms as a first step.

We consider a model in which local firms produce differentiated goods. These firms compete in an oligopolistic market. The government chooses the level of public policy (tax) imposed on pollution to maximize welfare. The model is set on a two-stage game. At the first stage, the government determines the tax level on pollution taking the firms' output levels as given. In the second stage, firms choose their output and emission levels observing the tax level set by the government. As usual, the problem is solved using backward induction. After exploring some comparative statics, we solve for optimal pollution taxation.

Producing ICEVs is cheaper than producing EVs and HVs. Firms have no incentives to produce ecologically efficient vehicles unless the environmental policies are strong enough. According to (15), (16), (24) and (25), in the case of severe pollution policy, the producers of the vehicles find profitable, in terms of cost, to produce EVs and HVs. In the model we developed, the amount of EVs is at most equal to the ICEVs, there is no empirical evidence suggesting the opposite with the actual technology.

Our results in (40) suggest that tax pollution is desirable when there is a high perception of the damage caused by pollution. Otherwise, the government is not willing to set a severe pollution policy. According to (43), a high perception of pollution damage encourages the setting of a pollution tax despite the fall in the consumer surplus and the profits of ICEVs producers. However, this policy encourages the production of EVs and HVs. On the other hand, low perception of pollution damage encourages the setting of a lax pollution policy since the government is taking into account the production efficiency over the environmental concerns. However, this policy discourages the production of EVs and HVs.

According to our model, it seems that the efficiency of pollution policies in terms of promoting responsible and efficient environmental policies depends on the perception of the damage caused by pollution given by the marginal disutility in (29). Many developing countries and some developed ones have failed in setting successful environmental strategies because they do not have developed social conciseness in terms of pollution damage, and they have prioritized the efficiency of the market more than the care of the environment. A larger environmental social conscience implies a strict environmental policy, and the proper incentives for the producer to adopt environmental technologies producing EVs reducing the cost in (16). The absence of this environmental social conscience results in increasingly worse environmental conditions and not cost is attached to produce ICEVs, firms tend to change from EVs to ICEVs as shown in (15).

Additionally, from (41), (42) and (43), when the firms tend to be homogenous, the pollution tax is smaller. Even when the pollution tax is positive given by a relatively high pollution disutility, when firms become homogeneous or, in other words, firms produce ICEVs, the government is setting a smaller pollution tax because the market requirements become important in the form of consumer and producer surplus.

This model shows that the application of environmental policies is only possible when there is an obvious perception of damage to the environment that can lead to vehicle pollution. According to Volkswagen (2019), the countries with the highest demand for electric vehicles are those that, in their public policy, are encouraged by a strong environmental awareness. In addition to that, most of the countries mentioned are developed. Hardly a developing country will sacrifice economic efficiency for a greener but more expensive option. The cost of an electric car in developing countries, where there are not enough tax incentives in favor of clean technologies, is prohibitive. The value of this work is to highlight that without a lower cost of producing electric cars, and better environmental awareness, the use of electric cars to improve environmental conditions is only a gesture of goodwill in most countries of the world.

Among the many limitations that this work has, being a theoretical work it is necessary to support the results from the econometric work. However, when modeling a stylized fact, it is a first approximation and future work should be econometrically oriented. On the other hand, this model assumes that the production of cars produced is subject to consumption within the same economy, and it is not the general reality of developing countries and only countries like Brazil, Argentina and Mexico have car manufacturers. Although in a strict sense this stylized fact is partially true in countries with car manufacturers, economic intuition is valuable when you consider not only the automotive market but also those markets with some impact on the environment.

A very interesting extension of this model would be to Parameterize the model. Parameterizing implies extending and enriching this analysis and would certainly be very positive for this article. We believe that a new article would be desirable where a necessary and enriching extension of this research would be to perform numerical simulations and analyze various parameterization schemes for this model.

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