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Strategic Environmental Policies in the Presence of Differentiated Goods

Políticas ambientales estratégicas en presencia de bienes diferenciados

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Abstract

We develop a theoretical model of partial equilibrium where firms, located in a country, compete and produce differentiated goods in a duopolistic market. Emission of pollution is related to production, and firms produce their output using different levels of polluting technology. To control pollution emission, the government applies discriminatory pollution quotas considering the benefits for firms, consumers, and environmental damage. The results show that if the disutility to be polluted is very high, the government imposes a zero-emission quota on the companies. But, if such disutility is not significantly high, it allows a certain amount of emissions, imposing different quotas on firms depending on the levels of technology they use to control their emissions. The proposed model stresses the importance of the rational establishment of strategic environmental policies, which benefit all economic agents in the market, firms, consumers, and the environment.

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Resumen

Desarrollamos un modelo teórico de equilibrio parcial donde las empresas, ubicadas en un país, compiten y producen bienes diferenciados en un mercado duopolístico. La emisión de contaminación está relacionada con la producción, y las empresas producen utilizando diferentes niveles de tecnología contaminante. Para controlar la emisión de contaminación, el gobierno aplica cuotas de contaminación discriminatorias teniendo en cuenta el beneficio para las empresas, los consumidores y el daño ambiental. Los resultados muestran que si la desutilidad a contaminar es muy alta, el gobierno impone una cuota de cero emisiones a las empresas. Pero, si dicha desutilidad no es significativamente alta, permite una cierta cantidad de emisiones, imponiendo diferentes cuotas a las empresas dependiendo de los niveles de tecnología que utilizan para controlar sus emisiones. El modelo propuesto subraya la importancia del establecimiento racional de políticas ambientales estratégicas, que actúen en beneficio de todos los agentes económicos en el mercado, las empresas, los consumidores y el medio ambiente.

Introducción

Human activities, in general, and the production of goods and services, in particular, have produced pollution negatively affecting the environment. The emission of huge amounts of toxic gases that cause the greenhouse effect (such as carbon dioxide, methane, and sulfur dioxide) is the main cause of global warming, desertification, deforestation, irreversible damage to ecosystems such as the extinction of animals and plants, rising sea levels, among others. On the other hand, the effects of pollution on human health are diverse. For instance, the risk of respiratory and cardiovascular diseases such as pneumonia and lung cancer are greatly increased by pollution. In this way, the ecological and economic costs of pollution are considerable (UNEP 2019).

The increase in population and economic growth causes a greater demand for goods and services, which causes the intensive use of the natural resources necessary for these production processes. The increasing demand and the intensive production are the origins of the increase in pollutant emissions. Governments should set environmental policies to regulate pollution emissions, but these policies must be flexible enough not to undermine the productivity of firms and their competitiveness. Governments all over the world face this dilemma; they must act with caution and intelligence, implementing environmental policies that guarantee economic growth and a healthy environment at the same time. For this, the government can establish some discriminatory environmental policies according to the level of contamination of each type of good produced, because the goods can be differentiated according to their polluting production technology.

As for the theoretical works that consider goods differentiated by the level of the cost structure to reduce pollution, the literature is quite scarce. In this sense, we develop a partial equilibrium model for a country with heterogeneous firms, under a Cournot duopolistic scheme. We assume that firms have the technology to reduce pollution, but with different levels of efficiency to control it. Therefore, the technological level determines the degree of product differentiation. In this sense, we can talk about the product differentiation causing one good to be more contaminated than another. Even when we do not intend to delve into a discussion between dirty and clean goods, for a more in-depth discussion on this issue see Stimming, 1999; Bayindir-Upman, 2000; Fullerton and Metcalf, 2002 and Requate, 2005.

Specifically in this paper, we consider that the government is setting a differentiated pollution quota according to the different levels of pollution technology of firms. To do so, the government considers the benefit of firms, consumers, and the social costs of pollution. Pollution quotas are quantitative limits to the amount of emissions applied to companies (Cropper and Oates 1992). In this sense, firms must assume the costs of reducing their emissions through appropriate technology to adjust to the amount of emissions determined by the government (Kolstad 2011).

These quantitative limits to the amount of emissions are determined by technological issues (Field, 2003). Generally, countries establish expert commissions that study the different industrial activities to determine, based on the analysis of available technologies, the associated costs, including monetary costs, average emission levels, and consultation with direct and indirect stakeholders, and the maximum amount of pollution emissions allowed per unit of product (Martínez-Alier and Roca Jusmet, 2000). In practice, it is sought that such quotas are economically viable for firms, that is, the costs to achieve them are not very high and are technically possible (Martínez-Alier and Roca-Jusmet, 2000). Likewise, there are many theoretical models that, based on empirical data and using various methodologies, determine the optimal amounts of pollutant emissions that depend, on the one hand, on the type of industry and its geographic location; and on the other, consider costs abatement, emission efficiency and total emission control.

There are many examples of the part of the application of pollution quotas to the industry, for example, the Automobile Protection Association of the United States, applies to the automobile industry, in the case of new automobiles, that each vehicle cannot emit in grams per kilometer the following: hydrocarbons without methane, 0.25; carbon monoxide, 3.4; nitrogen oxides, 0.4. For the electricity generating industry, the quality of the fuel is limited, thus, for example, the sulfur content cannot exceed 1%, or the emissions per quantity of fuel used, that is, they cannot emit more than 500 grams of sulfur dioxide per million BTUs of fuel used (Kolstad, 2011). In Europe, the European Environment Agency establishes quantitative limits on emissions into the atmosphere of certain pollutants from medium-sized industrial combustion facilities (with nominal thermal power equal to or greater than 1 MW and less than or equal to 5 MW), measured in mg / Nm3, for example, for nitrogen oxides are 650 for solid fuels, 200 for diesel and 250 for natural gas (European Union, 2015)).

In terms of differentiated pollution quotas, Golombek and Hoel (2008) analyze the allocation of pollution quotas under conditions of cooperation between two countries, where the costs of reducing pollution are determined through investments in research and development, that is, pollution control technologies. Golombek and Hoel (2006) develop a model where investments in research and development are corrected through an internal subsidy. Endres and Rundshagen (2013) study the incentives for firms and the innovation of technology to control their emissions under an international environmental cooperation scheme; they conclude that technology innovation is not necessarily optimal when quotas are applied as an emission control instrument. Differing from the previous models, we consider that the pollution quota is the main endogenous variable, and the determination of its optimal value determines the environmental policies that the government implements to maximize general welfare.

Regarding the theoretical models that consider emission quotas and the Cournot oligopoly scheme, we can mention Montero (2002), Lahiri and Ono (2000) and Kayalica and Lahiri (2005). Montero (2002) compares the environmental R&D incentives, through the application of quotas, through 4 environmental control instruments (emission standards, performance standards, negotiable permits, and auctioned permits), under the categories of oligopoly permits and product markets. In this model, incentives depend on direct and strategic effects, standards can offer greater incentives than permits. Also, if markets are perfectly competitive, tradable, and auctioned permits offer equal incentives, similar to emission standards and generally more than performance standards. The model developed in this study does not consider the presence of R&D incentives, so it focuses on the application of environmental policies applied by the government generically using pollution quotas, under the duopolistic scheme of a differentiated good by the level of technological efficiency.

Lahiri and Ono (2000) consider the application of taxes and pollution quotas when an endogenous number of foreign firms compete against domestic firms in the market for a non-tradable good produced under oligopoly conditions. They conclude that the magnitude of the marginal abatement cost determines the optimal environmental policy. On the other hand, Kayalica and Lahiri (2005) analyze the application of the quota policy under an oligopolistic FDI scheme, in which foreign firms located in a host country compete against a domestic company in another country to export a homogeneous good to a third-party country. When the number of foreign firms is exogenous, the host country applies stricter environmental regulations than the other producing country. On the other hand, under conditions of free entry and exit of foreign firms, the host country can apply a less severe standard in both the non-cooperative and cooperative equilibrium. Unlike the work of Lahiri and Ono (2000) and Kayalica and Lahiri (2005), although our work does not consider the presence of FDI, we consider the most realistic assumption of differentiated goods, although we closely use the Lahiri and Ono model as a basis in modelling.

Regarding the theoretical models under oligopoly conditions with horizontally differentiated goods, we can mention Fujiwara (2009) and Gautier (2015). Fujiwara (2009) builds a polluting oligopoly model with differentiated goods, he considers how product differentiation, together with the presence and absence of free entry, affects the optimal pollution tax policy. Gauthier (2014) examines the role of horizontal product differentiation in optimal policy and industry emissions in a Cournot oligopoly model in the presence of emission abatement technology, subsidies, and taxes. He concludes that, as products become more differentiated, the government can afford a tax increase due to the presence of subsidies and abatement technology. In this work, compared to the previous ones, taxes are not used; but quotas and the nature of product differentiation in our model determine the level of technological efficiency.

Among other works that establish environmental quotas in product differentiation models under the duopoly scheme, we can mention Moraga-González and Padron-Fumero (2002), Espínola-Arredondo and Zhao (2012), and Arguedas and Rousseau (2021). Moraga-González and Padron-Fumero (2002) study the impact of some frequently used environmental policies in a duopolistic market, among them pollution quotas, where buyers are willing to pay more for less polluting goods, conditioned by a certain level of environmental awareness. They establish that the ecological characteristics of the product are determined by the level of environmental awareness of consumers, while in our model it is determined by the level of technological efficiency.

Espínola-Arredondo and Zhao (2012) analyze how a tax and subsidy policy affects the behaviour of consumers when choosing between organic goods and conventional products, and its effects on well-being when a proportion of consumers have strong preferences for organic products. They conclude that, under a framework of horizontal product differentiation, an environmental regulation generates greater social welfare than the absence of an environmental policy. On the other hand, our work differs in that it does not use the linear city assumption in product differentiation, but rather the technological efficiency approach, and also differs in the how quotas are used as an instrument of environmental policy.

Arguedas and Rousseau (2021) analyze the behaviour of consumers determined by their environmental awareness, the application of subsidy policies, product standards (which can force companies to supply products that are more energy efficient) and education to improve the environmental performance of companies through the design of energy-efficient products. They conclude that a policy based on a product standard can counteract the negative effects of displacing the intrinsic motivation of consumers in a monopoly environment, although this counteracting effect is less powerful under a duopoly. However, in the subsidy policy, the total effect of the displacement will be significant. In this sense, our work differs from the previous one in that it focuses on quotas, which does not consider the monopoly scheme, and on the nature of differentiation through the technological efficiency of firms.

Finally, Sandoval and Espinosa (2020) develop a theoretical FDI model for the market of a homogeneous good, foreign firms compete against national firms under duopolistic conditions, they use the differentiated pollution quota as a control instrument, and it is assumed that companies of foreign direct investment have more efficient technology to reduce pollution. It is concluded that if the disutility to be polluted is considerably high, the government of the host country imposes a zero-pollution quota on both local and foreign companies; but if the disutility to be polluted is not very high, the government allows these companies a certain amount of emissions depending on the relative efficiency of each type of company. In this sense, the model proposed here differs from the previous one in the product differentiation in terms of the cost structure associated with pollution control; in such a way that the application of environmental policy considers the efficiency of technology in determining the optimal quotas by maximizing the well-being of all the economic agents involved.

So, we consider a model in which local firms produce differentiated goods. These firms compete in a duopolistic market. The government chooses the level of public policy (pollution quota) imposed on pollution to maximize welfare. The model is composed of two stages. At the first stage, the government determines the level of pollution quota taking the firms' output levels as given. In the second stage, firms choose their output and emission levels observing the pollution quota set by the government. As usual, the problem is solved using backward induction.

In this article, there are three characteristics not addressed by literature altogether, and that also makes the modelling of stylized facts closer to reality. First, the use of discriminatory environmental policies allows solving the efficiency problem that the uniform environmental policy does not consider. Second, the existence of differentiation in terms of the firms' cost structure is considered, in such a way that the firm decides the level of pollution based on the cost of abating it. Third, consumers recognize the polluting nature of goods, even if they do not know the technology necessary to produce them. Therefore, the government can establish a discriminatory environmental policy, in the form of pollution quotas, which is more efficient in terms of social welfare. This policy of discriminatory quotas would depend on the disutility of pollution, the cost of reducing pollution by the polluting company, and the benefit of the consumer.

The importance and contribution of this article lie in the analysis of discriminatory environmental policies in the context of competition between polluting and non-polluting companies, where the cost of the former is lower than the cost of the latter according to most of the literature. In this sense, the consumer, knowing about the polluting nature of the goods, considers it beneficial that there is a difference between the prices of the goods since the polluting good provides him with a greater surplus than does the non-polluting good. Firms know this and henceforth decide their level of production and level of pollution. The government maximizes social welfare by considering both environmental conditions and market efficiency.

This article models a clear reality that occurs in many developing countries where the implementation of environmental policies can undermine their economic efficiency, and discriminatory environmental policies have become an option in their economic-environmental dilemma. We recognize that the assumption of a discriminatory environmental policy may be questionable in contexts where the regulator does not have perfect information on each regulated company. Certainly, the information that the government has may be limited. However, there are cases in which, in certain sectors, there is sufficient information on the environmental impact of companies. There are government agencies that obtain this information due to specific monitoring of the sector. An example is in the tourism sector where there is timely monitoring of the impact of environmental carrying capacity on ecosystems. We assume a discriminatory environmental policy as in Deng (2021), Erdogan (2013), and Kayalica and Lahiri (2005).

Probably the most relevant aspect of this article is the context in which it is modelled, and the fact that the model can consider that the absence of an environmental policy may be optimal in some economic contexts, especially in low- and middle-income countries.

After exploring some comparative statics, we solve for optimal pollution quota. The basic economic model is spelt out in the following section. Section 3 then carries out a comparative statics analysis for the basic model. The optimal policy is analysed in section 4. Finally, some concluding remarks are made in section 5.

1. Model Framework

We use the simplest possible structure capable of presenting the main points. In this model, there are two firms a and b, both firms produce differentiated and non-tradable commodities in terms of cost and demands. We have exogenous horizontal differentiation, firm a produces a commodity with a polluting technology, and firm b may produce a commodity with a different level of polluting technology: firm b may use a polluting technology like firm a, or clean technology, or something in between. The election of the level of polluting technology 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. 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 outputs 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 output produced by firm a, x_b is the output produced by firm b, and γ is the degree of differentiation such that $1 \geq \gamma \geq 0$. When $\gamma = 1$, both outputs are perfectly homogenous and are produced by a polluting technology, and we have only one demand function. When $\gamma = 0$, both outputs are differentiated and firm a produces output with a polluting technology and firm b produces output with a non-polluting (or clean) technology. However, when we have a value between zero and one, it means we have somewhat of a polluting technology used by firm b. This partially polluting technology may have a different degree of environmental cleanness according to the level of differentiation.

The degree of differentiation of a good depends on the consumer's perception of the attributes of the product. In this case, the differentiated good has different attributes, but satisfies the same need as the final consumer. The consumer recognizes that two goods are imperfect substitutes but does not know about the technology with which these goods were made.

The fact that the consumer does not recognize the technology with which differentiated goods are made is common in societies with low environmental literacy. Even when they know that the technology used to produce a certain good is polluting or not, it does not necessarily imply that consumer preferences change. Kollmuss and Agyeman (2002), Chartand (2005), and recently Siegel, Cutter-Mackenzie-Knowles and Bellert (2018) have shown that there is a gap between environmental knowledge and the specific behaviours achieved by individuals because of their environmental awareness. In this sense, these studies have been carried out analyzing these differences between environmental knowledge, the level of ecological awareness, and real behaviour that individuals manifest in caring for their natural environment.

In this paper, we consider that there is a gap between environmental knowledge and specific environmental behaviours. We assume that, even though consumers might know the technology used to produce the differentiated goods, this does not imply that they have any environmental behaviour as shown by Kollmuss and Agyeman (2002), Chartand (2005), and Siegel, Cutter-Mackenzie-Knowles and Bellert (2018).

However, incorporating environmental behaviour into the model can be straightforward. The simplest option is that the degree of differentiation affects consumer preferences. That is, the higher the level of differentiation, the lower the willingness to consume the goods with polluting technology. Rewriting the demand functions, we may have

$$p_1 = a_1 - bD_a$$
$$p_2 = a_2(\gamma) - bD_b$$

The first demand is for non-polluting technology goods and the second is for polluting technology goods. The intercept of the first demand a_1 is fixed, the intercept of demand of the second equation is a function of the level of environmental awareness (α), such that $a_2 = a_2(\alpha)$, and it is decreasing ($a_2' < 0$). In other words, larger the level of environmental awareness, smaller is the willingness to consume the polluting good. However, we consider this is another extension of the model and we omitted it for simplicity. We consider that the consumer is not generally concerned with the environment as pointed out by Kollmuss and Agyeman (2002), Chartand (2005), and Siegel, Cutter-Mackenzie-Knowles and Bellert (2018).

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 a duopolistic 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 a 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 (9) and (10) into (5) and (6) 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 under a polluting technology, firm b may produce under a non/partial/total polluting technology. 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 output implies adopting more expensive technology. In other words, when $\gamma = 1$ both outputs are homogenous and both firms produce using the same polluting technology, and when $\gamma = 0$ both outputs are differentiated and firm b produces using a non-polluting technology and firm a produces goods using a polluting technology. Something in between $(1 > \gamma > 0)$ means that firm b produces using a partial polluting technology. As a simplifying assumption, we do not consider the decision of firms to use an environmental technology level, nor the incentives they may receive if they adopt a specific technology. An extension of this model would be to endogenize this firm's decision in interaction with the government's optimal policy decision. In this article, only the different possible scenarios are seen in the optimal policy at different levels of differentiated goods. The structures of cost in both firms are

$$k_a = c_a + \lambda\theta_a \quad (13)$$
$$k_b = c_b(\gamma) + \lambda\theta_b(\gamma) \quad (14)$$

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 for firm a. However, this cost in firm b is determined by the degree of differentiation $c_b = c_b(\gamma)$, where $c_b' < 0$ and $c_b'' = 0$ we have a linear relation. The cost of firm b is bounded 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 environmental technology is more expensive than adopting the normal polluting technology. 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 production technology 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 outputs are homogenous such that $\theta_b(1) = \theta_a$, but with completely differentiated outputs, the technology of production is less polluting in firm b than in firm a such that $\theta_b(0) = 0$. So, we can consider a linear relation in which $\theta_b' > 0$, and $\theta_b'' = 0$. 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

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

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

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

With no pollution policy, and given the cost difference, the output produced by the firm a is at least as larger as the output produced by firm b. Finally, from (11) to (14) we get

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

We have that $\pi_a - \pi_b \geq 0$.

Here, we wonder how pollution may affect the health of 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, for example, pollution quota, to control the emission of pollution to avoid environmental degradation. Following Lahiri and Ono (2000), we consider a pollution quota, which may affect the production decision, and therefore, the amount of pollution emitted into the atmosphere. The cost structure would be rewritten from (13) and (14) as

$$k_a = c_a + \lambda(\theta_a - z_a) \tag{15}$$
$$k_b = c_b(\gamma) + \lambda(\theta_b(\gamma) - z_b) \tag{16}$$

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 quota has associated with 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.

To set an optimal policy, the government is willing to set a pollution policy considering the health benefits of people, and the reduction in consumer and producer surplus given by the increase in production costs. The government maximizes a welfare function like:

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

where the first two terms are the producer surpluses, the third term is the consumer surplus, and the fourth term is the pollution disutility where ψ is the marginal pollution disutility, and R is the amount of pollution emitted into the atmosphere. The social cost of polluting refers ideally to the monetary value of correcting the environmental damage caused by pollution. Although in practice, this cost is difficult to calculate, it is feasible to have the *proxy* to measure it. The marginal social cost of polluting is called marginal disutility (see Hussen 2018). However, we can consider that the marginal pollution disutility may be a perception that depends on social-environmental awareness. People may perceive or may not perceive that pollution is a harmful phenomenon.

The consumer surplus is defined as $CS = CS_a + CS_b$ such that from (1) and (2) we get

$$CS_a = \frac{D_a^2}{2} \tag{18}$$
$$CS_b = \frac{D_b^2}{2} \tag{19}$$

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 quota for each firm $z_i{}^*$. The model is set on a two-stage game. At the first stage, the government determines the quota level of pollution taking the firms' output levels as given. In the second stage, firms choose their output and emission levels observing the pollution quota level set by the government. As usual, the problem is solved using backward induction. With these equations and the game-theoretic structure, we complete the model specification and turn to its analysis in the following sections.

2. Comparative Statics

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

$$\frac{dk_i}{dz_i} = -\lambda < 0 \tag{21}$$

An increase in pollution quota reduces the cost of firms because more pollution emission is allowed and the cost for abating pollution is reduced. By (21) we consider that the impact of quota on costs affects the optimal output produced. From (9), (10) and (21) we have

$$\frac{dx_a}{dz_a} = \frac{dx_b}{dz_b} = \frac{2\lambda}{4-\gamma^2} > 0 \tag{22}$$

$$\frac{dx_a}{dz_b} = \frac{dx_b}{dz_a} = -\frac{\lambda\gamma}{4-\gamma^2} \leq 0 \tag{23}$$

Unambiguously, an increase in the allowed pollution quota of a firm affects positively the output produced by both firms. Increasing the allowed pollution, the cost of both firms is smaller, and the output increases. However, the impact of an increase in the allowed pollution quota of one firm on the output of the other firm depends on the degree of differentiation. When $\gamma > 0$, the result in (23) is negative. Any increase in the pollution quota allowed in one firm reduces the production of the other firm because the first firm obtains a competitive advantage over the last one, given by the reduction in the cost of reducing pollution, there is a cost advantage in the first firm over the last firm. When both goods are completely differentiated ($\gamma = 0$) an increase in pollution quota does not affect the output of the other firm because there is no competitive relation between firms, there is not an oligopolistic interdependence. From (11), (12), (22) and (23) we have

$$\frac{d\pi_a}{dz_a} = \frac{4x_a\lambda}{4-\gamma^2} > 0; \ \frac{d\pi_a}{dz_b} = -\frac{2x_a\lambda\gamma}{4-\gamma^2} \leq 0 \tag{24}$$

$$\frac{d\pi_b}{dz_b} = \frac{4x_b\lambda}{4-\gamma^2} > 0; \ \frac{d\pi_b}{dz_a} = -\frac{2x_b\lambda\gamma}{4-\gamma^2} \leq 0 \tag{25}$$

The intuition is like the previous case, since the firms' profits increase with an increase in their allowed pollution quota due to a reduction in costs, and the firms' profits decrease with an increase in the firm's allowed pollution quota of the competing firm because of its cost disadvantage. To obtain the comparative static of consumer surplus, we have from (16), (17), (22) and (23) the following

$$\frac{dCS_a}{dz_a} = \frac{\lambda(2-\gamma^2)D_a}{4-\gamma^2} > 0 \tag{26}$$
$$\frac{dCS_a}{dz_b} = \frac{\lambda\gamma D_a}{4-\gamma^2} > 0 \tag{27}$$
$$\frac{dCS_b}{dz_a} = \frac{\lambda\gamma D_b}{4-\gamma^2} > 0 \tag{28}$$
$$\frac{dCS_b}{dz_b} = \frac{\lambda(2-\gamma^2)D_b}{4-\gamma^2} > 0 \tag{29}$$

Independently of the level of differentiation, the consumer surplus increases with an increase in the pollution quota allowed for any firm. However, the level of differentiation defines the level of impact on consumer surplus. When $\gamma > 0$, an increase, for instance, in the allowed pollution quota of a firm a will reduce its cost, increasing its output. On the other hand, firm b faces a competitive disadvantage in reducing its output. The increase in the output of firm a is larger than the reduction in the output of firm b, and the price goes down. When both commodities are completely differentiated ($\gamma = 0$) an increase in the pollution quota does not affect the output of the other firm, and the increase in consumer surplus is given just by the increase in the corresponding output.

Finally, the impact of a pollution quota on people's health is given by

$$\frac{d(\psi R)}{dz_a} = \psi x_a + \frac{\lambda\psi(2z_a-\gamma z_b)}{(4-\gamma^2)} \tag{30}$$
$$\frac{d(\psi R)}{dz_b} = \psi x_b + \frac{\lambda\psi(2z_b-\gamma z_a)}{(4-\gamma^2)} \tag{31}$$

There is an ambiguous impact of an increase of pollution quota on pollution disutility given by the increase and decrease in the output. When both commodities are completely differentiated ($\gamma = 0$), an increase in the pollution quota unequivocally increases the amount of pollution emitted into the atmosphere, and the negative impact on people's health. When $\gamma > 0$, an increase in the allowed pollution quota of any firm is ambiguous, which depends on the amount of pollution allowed by the government for both firms.

3. Optimal Pollution Quotas

Once we have set some comparative statics, we derive the optimal pollution quota. Total derivation of (17) with respect to the optimal pollution quota, and considering (21) to (31) we get

$$dW = \left[\frac{4\lambda x_a}{4-\gamma^2} - \frac{2\lambda\gamma x_b}{4-\gamma^2} + \frac{\lambda(2-\gamma^2)D_a}{4-\gamma^2} + \frac{\lambda\gamma D_b}{4-\gamma^2} - \psi x_a + \frac{\lambda\psi(\gamma z_b - 2z_a)}{4-\gamma^2}\right] dz_a + \left[\frac{4\lambda x_b}{4-\gamma^2} - \frac{2\lambda\gamma x_a}{4-\gamma^2} + \frac{\lambda(2-\gamma^2)D_b}{4-\gamma^2} + \frac{\lambda\gamma D_a}{4-\gamma^2} - \psi x_b + \frac{\lambda\psi(\gamma z_a - 2z_b)}{4-\gamma^2}\right] dz_b \tag{32}$$

Here, we set the impact of a discriminatory pollution quota on the welfare of the country. Solving the coefficients in (32) as a simultaneous system we get the optimal pollution quotas for each firm as

$$\lambda\psi z_a^* = \lambda(3x_a + \gamma^2 x_a + 2\gamma x_b) - \psi(2x_a + \gamma x_b) \tag{33}$$
$$\lambda\psi z_b^* = \lambda(3x_b + \gamma^2 x_b + 2\gamma x_a) - \psi(2x_b + \gamma x_a) \tag{34}$$

The optimal pollution quota for each firm depends on the marginal pollution disutility, the unit cost for abating pollution and the degree of differentiation. To have a feasible solution, we get the second-order condition so that this condition holds when

$$\frac{d^2W}{dz_a^2} < 0, \frac{d^2W}{dz_b^2} < 0 \text{ and } \frac{d^2W}{dz_a^2}\frac{d^2W}{dz_b^2} - \frac{d^2W}{dz_a dz_b}\frac{d^2W}{dz_b dz_a} = H > 0$$

From here we have:

$$\frac{d^2W}{dz_a^2} = \frac{d^2W}{dz_b^2} = [\lambda(12+\gamma^4-\gamma^2) - 4\psi(4-\gamma^2)]\frac{\lambda}{(\gamma^2-4)^2} < 0$$
$$H = \big(\lambda(-2\gamma+\gamma^2+3) - 2\psi(2-\gamma)\big)\big(\lambda(2\gamma+\gamma^2+3) - 2\psi(2+\gamma)\big)\frac{\lambda}{(\gamma^2-4)^2} > 0$$

Under any level of differentiation (γ), the second-order condition holds when $\psi \geq \lambda$: the marginal pollution disutility should be equal or larger than the unit cost for abating pollution.

Under the second-order condition, from (33) and (34), we can see that the optimal pollution quota for each firm depends on the difference between the marginal pollution disutility and the unit cost for abating pollution. When the marginal pollution disutility is sufficiently large, the optimal pollution quota is zero; meaning that the government does not allow pollution at all. Of course, mathematically speaking the optimal pollution quota may be negative, but in fact, there is no negative pollution quota. On the other hand, when the marginal

pollution disutility is small and close enough to the unit cost for abating pollution, the optimal pollution quota is positive. Formally we can say:
Proposition 1. *Under duopolistic competition and in the presence of differentiated commodities, the optimal discriminatory pollution quotas are positive when the marginal pollution disutility is small enough, and zero when the marginal pollution disutility is sufficiently large:*

If $\psi \rightarrow \lambda$, *then* $z_a^* > 0, z_b^* > 0$
If $\psi \gg \lambda$, *then* $z_a^* = 0, z_b^* = 0$

Intuitively speaking, with a negligible marginal pollution disutility, the benefit of a positive pollution quota on consumer surplus and producer surplus is larger than the harm caused by the pollution on people's health. Promoting production to benefit consumption and production seems to be the best option of the government independently of the pollution consequences since the impact and perception of pollution on people's health is negligible.

On the other hand, when the pollution disutility is sufficiently large, the government has incentives to set a positive pollution quota for both firms, because the environmental concern on people's health is larger than the possible loss in producer and consumer surplus for setting a strict environmental policy.

However, the optimal pollution policy would be different depending on the polluting technology used by each firm. We consider that the degree of differentiation is a variable considered by the government when setting a pollution policy. To make a clear analysis, we consider only the case in which the optimal pollution quotas are positive when marginal pollution disutility is close enough to the cost for abating pollution ($\psi = \lambda$). Making this assumption, from (33) and (34) we have,

$$z_a^* = (x_a + \gamma^2 x_a + \gamma x_b)/\lambda \tag{35}$$
$$z_b^* = (x_b + \gamma^2 x_b + \gamma x_a)/\lambda \tag{36}$$

From (35) and (36), is straightforward to see that pollution quotas increase as the degree of differentiation increases. When disutility from pollution is low, the government allows firms to pollute. The more homogeneous the cost structure of both companies, the levels of both companies tend to equalize, improving consumer and producer surplus, therefore the government allows a higher pollution quota. However, when $\gamma = 0$, the allowed pollution quota of firm b is zero. By (16), the amount of pollution emitted by firm b is zero ($\theta_b = 0$), and it does not make sense to set any pollution quota policy for this firm. On the other hand, by (35), we can see that the allowed pollution quota of firm a is positive under any differentiation level.

When $\gamma = 1$, the cost structure of both firms is identical and so the optimal output produced by both firms, so we can conclude that the allowed pollution quota for both firms is the same. Considering the last arguments, we can define the difference between both pollution quotas. From (35) and (36) we get

$$z_a^* - z_b^* = \frac{(x_a - x_b)(\gamma^2 - \gamma + 1)}{\lambda} \tag{37}$$

Here, (37) seems ambiguous, and it depends on the amount of output produced by each firm according to the different levels of differentiation. When the output produced by the firms are completely differentiated ($\gamma = 0$), there is no pollution quota for firm b, so we can say that $z_a^* > z_b^* = 0$. In the case in which both products are completely homogenous ($\gamma = 1$), then $x_a = x_b$, and $z_a^* = z_b^*$ such that (37) is zero.

As mentioned before, adopting environmental technology is more expensive than normal non-environmental technology, so the output produced by firm a is at least as large as the output produced by the firm b. It means ($x_a - x_b \geq 0$). So, under any level of differentiation, the allowed pollution quota of the firm a is larger than the allowed pollution quota of firm b, such that $z_a^* \geq z_b^*$. Formally we can say,

Proposition 2. *Under duopolistic competition, and when the level of pollution disutility is small enough, the optimal pollution quota of the polluting firm is at least as large as the pollution quota of the non-polluting firm, depending on the level of differentiation.*

Intuitively speaking, when the level of marginal pollution disutility is negligible, the government in the host country is willing to privilege the consumer and producer surplus over the environmental concerns. In such a case, the setting of positive pollution quotas would be larger for the firm with a lower cost. The government would allow the firm with lower cost to pollute more to guarantee a larger consumer and producer surplus. The more environmentally friendly firm does not need a larger pollution quota allowance, they emit less pollution anyway.

Under this case in which the marginal pollution disutility is relatively small, we conclude that the firms are reluctant to adopt clean technology due to higher costs. Given that the government is privileging the consumer surplus and the benefits of firms over the consideration of the environment, the benefits obtained by a firm using clean technology would be inferior to the benefit obtained by a firm using polluting technology. There is no way in which the government may promote the adoption of clean technology by firms.

Conclusions

The relationship between pollution control and the production of goods and services is a permanent consideration in economic welfare models. This work analyzes how the government applies pollution quotas, as an instrument of environmental policy to guarantee economic well-being and a healthy environment, to heterogeneous firms. In this sense, we have discriminatory pollution quotas given by the heterogeneity of firms, a discriminatory quota may promote some environmental efforts made by firms to promote the adoption of clean technology.

In this model, the production of goods manufactured by companies is differentiated by the adoption of a specific technological environmental level and is considered in the control of their toxic emissions. The firms compete under a Cournot duopolistic scheme. The optimal discriminatory quotas were calculated taking the firm's heterogeneity and their benefits into account, consumer surplus and the environmental impact caused by pollution on people. We get the following conclusions:

If the marginal pollution disutility is significantly high, the government imposes the maximum possible restriction: a zero quota of emission of pollutants. The government, regardless of the environmental technology used by a firm, considers that the damage of pollution to the environment is relevant and, consequently, is affecting people's health. For the government, the benefit of strict pollution control on people's health is greater than the loss in producer and consumer surplus. This is intuitively clear.

In this case, adopting clean technology seems to be a good option for firms because there is no cost attached to abate pollution. However, the cost of adopting such clean technology is larger than the cost for not adopting clean technology as we assumed at the beginning of the paper. Despite the government setting a strict environmental policy and considering that only the firm with conventional polluting technology abates all its emitted pollution, the benefit of this firm polluting is larger than the benefit of the clean technology firm unless the cost for abating pollution becomes larger than the cost for adopting a clean technology.

In the opposite sense, if the marginal pollution disutility is negligible, the government promotes the production of firms and the consumption of people. We have lax pollution control over firms. The benefit in consumer and producer surplus is greater than the loss of people's health. However, since there may be technical differences between firms to control their emissions, the government allows a greater amount of pollution from the firm with less environmental technology, favoring its competitiveness. On the other hand, the government allows less pollution from the firm with more environmental technology. Of course, there are no incentives for firms to adopt clean technology.

Summarizing, the proposed model emphasizes the importance of the rational establishment of strategic environmental policies, which act for the benefit of all economic actors in the market, firms, consumers, and the environment; when selecting those policies that also lead to the sustainable development of the economy, all these elements are integrated into the general welfare function.

The results in this paper are valuable since the existence of expensive pollution technologies and a poor perception of the damage done by pollution may undermine any attempt to set environmental policies. Both are relevant variables to understand the relative efficiency of setting pollution policies in some countries. Cheaper environmental technologies and higher social-environmental awareness may change the result of the model.

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