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Giulia Ceccantoni, Ornella Tarola, Cecilia Vergari

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SAPIENZA - UNIVERSITY OF ROME
P.le Aldo Moro n.5 – 00185 Roma T(+39) 0649910563
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Tax and pollution in a vertically differentiated duopoly: when consumers matter.[*]

Giulia Ceccantoni,[†] Ornella Tarola,[‡] Cecilia Vergari[§]

Abstract

Inspired by the so-called polluter pays principle, environmental taxes can drive a more sustainable European market. However, unilateral mitigation measures can reduce the competitiveness of carbon-intensive industries, thereby inducing relocation. In this paper, we wonder whether a tax can effectively curb emissions without hurting firms. Our analysis's entry point is that the level of emissions in a region is jointly determined by (i) the number of consumers buying dirty goods and (ii) the environmental quality of these products. Thus, to curb emissions, on the one hand, firms have to reduce their goods' emissions intensity. On the other hand, consumers have to reduce the consumption of dirtier goods. This leads to defining a tax whose burden depends on the *number of consumers* buying the brown products and the *relative quality* of these products. We show that under this tax, lower emissions do not come at the expense of lower profits.

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[†]Memotef, Sapienza University, Via del Castro Laurenziano 9, 00161 Roma, Italy. E-mail address: giulia.ceccantoni@uniroma1.it.

[‡]Disse, Sapienza University, Piazzale Aldo Moro 5, 00185 Roma, Italy. E-mail address: ornella.tarola@uniroma1.it.

[§]Department of Economics and Management, University of Pisa. E-mail address: cecilia.vergari@unipi.it.

1 Introduction

> "Approximately 1.7 billion people worldwide now belong to the "consumer class"—the group of people characterized by diets of highly processed food, desire for bigger houses, more and bigger cars, higher levels of debt, and lifestyles devoted to the accumulation of non-essential goods. Today nearly half of global consumers reside in developing countries, including 240 million in China and 120 million in India—markets with the most potential for expansion."(National Geographic, 2004).

Inspired to the so called *polluter pays principle* and advocated by the European Green Deal as drivers toward a greener and more sustainable European market, environmental taxes are "those whose tax base consists of a physical unit (or similar) of some material that has a negative, verified and specific impact on the environment" (Eurostat, 1997). They represent a direct way for the economic agents to consider the environmental effects of their decisions. Opponents of carbon taxes point out, however, that unilateral mitigation measures reduce the competitiveness of carbon-intensive industries, thereby inducing relocation – rather than tax compliance – and, as a by-product, carbon leakage effects.[1]

Although the empirical evidence on relocation and carbon leakage effects is mixed, the theoretical arguments against carbon tax fuel skepticism about its effectiveness in abating emissions without penalizing industries' competitiveness (Petrakis and Xepapadeas, 2003). Our paper's scope is to analyze whether an endogenous environmental tax can be useful in curbing emissions without sacrificing firms' profits.

Casual observations show that European countries are somewhat familiar with environmental taxes and periodically adjust their measures to keep up with the rising trend of consumption possibilities and technological advancements. It comes with no surprise that Governments revise their green measures following the growing environmental skills of producers. Since 2008, Finland, Ireland, the Netherlands, and other countries have introduced emissions differentiated ad valorem taxes. In Italy, tax exemption is provided to cleaner vehicles, and road circulation is periodically restricted to the less pollutant cars in areas with high traffic density. In Israel, where pollution and congestion coming from

[1] Carbon leakage occurs when a unilateral climate policy aimed at abating emissions in a region/country determines an increase in emissions in another region. See Sanna-Randaccio *et al.* (2017) to discuss the short-term and long-term drivers of this phenomenon.

a high number of polluting vehicles are significant, a green reform was introduced in 2009 with the primary aim of differentiating the taxation of car purchases depending on their emission levels. In 2013, following the falling volume of polluting vehicles, this taxation was updated. Currently, it is adjusted every two years. Finally, scrapping programs encourage consumers to switch from dirtier to cleaner variants of products.

This empirical evidence represents our analysis's key ingredient: we design a tax whose traits are defined based on a relative environmental quality (henceforth RQ): a product is not polluting per se, but relatively to a cleaner variant. This relative dimension of quality grasps the idea that policymakers implement their plan while considering the ongoing process of decarbonization and the availability in the market of products with lower and lower environmental impact. We show that this RQ tax reduces producers' profits, whereas its effects on the environment are ambiguous. In particular, we prove that if the fiscal burden is high, the tax raises global emissions**.**

This result suggests that an RQ tax reduces the competitiveness of carbon-intensive industries and, in the case of unilateral mitigation measures, it can induce relocation and carbon leakage effects without generating clear environmental gains. Accordingly, it represents the natural entry point for the second line of research. We consider an alternative modeling choice that is inspired by the commonly shared idea that the level of emissions in a region is jointly determined by (i) the emissions intensity of dirty goods and (ii) the number of consumers buying these goods. This obvious consideration has a very significant implication. On the one hand, to curb emissions, firms have to improve the environmental quality of their goods, thereby reducing their per-unit emissions intensity.

On the other hand, consumers have to reduce the consumption of dirtier goods, thereby preferring cleaner variants. This claim immediately leads to defining a tax whose burden depends on both the relative quality of these products and the number of consumers buying the brown products, say an N-RQ tax. We show that this tax is effective in curbing emissions without reducing firms' profits.

The theoretical argument that brown consumption behavior is a source of pollution and a social phenomenon supports our approach. Whenever most people are accustomed to using dirtier products, brown consumption can be somehow accepted as a common practice since social constraints motivating an environmentally friendly behavior are absent (see, e.g., Allcott 2011, Nyborg et al. 2006, Czajkowski et al. 2015). In a community where a brown lifestyle does not provide any social/psychological penalty beyond the material needs that products traditionally satisfy, people do not feel any social stigma when purchasing brown products (Ben Elhadj and Tarola, 2015). Even worse, the environmental damage that these products generate are sometimes only slightly perceived. In these circumstances, enhancing the switch from dirtier to cleaner products requires a massive effort from the policymaker to counterbalance a consolidated, widespread habit rather than an occasional behavior. Symmetrically, whenever the use of dirtier products is reduced, the amount of tax incentives can be lower.

Our formal analysis

Formally, we consider two firms offering variants with different emission intensities per unit of production. This modeling strategy puts our analysis in the theoretical framework of vertically differentiated products (e.g., Moraga-Gonzalez and Padron-Fumero, 2002; Lombardini-Riipinen, 2005; Ben Elhadj and Tarola, 2015). On the demand side, the market is populated by heterogeneous consumers willing to pay a price premium for the eco-friendly variant. In this setting, a relative tax, increasing with the environmental quality gap between the cleaner and the dirtier variant, targets consumers. The quality gap is endogenously determined by firms and captures the relative environmental quality of the dirtier product. The larger the gap, the lower this quality compared to the cleaner one.

We characterize the equilibrium configuration of the market in a two-stage game. Firms compete at the first stage in environmental quality and the second stage in price. We compare this equilibrium with what is observed when a consumers-based tax is related to a quality dimension but considers the number of consumers buying the brown product. Firms can encourage consumers to switch from dirtier to cleaner variants via relative prices. Symmetrically, consumers can incentivize firms to increase the environmental quality of their products through demand. Then, we briefly discuss how our findings change when this tax is on the polluting producer.[2]

To the best of our knowledge, we are the first to design a tax differentiated along two dimensions: a relative quality dimension and a quantity driver. Typically, the entry point of the literature in vertically differentiated markets is mainly an ad-valorem tax (Cremer and Thisse 1994, Moraga-Gonzales and Padron-Fumero 2002, Bansal and Gangopadhyay 2003) or an emission tax (Karakosta 2018). The relative quality puts our

[2] Notice that this is in contrast with the RQ scenario, where the environmental effects of the tax do not change with the recipients –consumers or firms– of the tax.

paper particularly close to Lombardini-Riipinen (2005) where, in a vertically differentiated market with an ad valorem tax on firms, a subsidy is paid to green consumers depending on the quality gap between variants. In Lombardini-Riipinen (2005), this subsidy is however, unrelated to the number of consumers buying one of the two variants existing in the market. A similar approach is in Toshimitsu (2010) where a subsidy is based on the quality gap between two different variants' environmental quality.

As far as the quantity driver is concerned, contributions are investigating environmental quality competition and taxation in the presence of green network effects (like Brécard, 2013). However, these approaches lay on the assumption that consumers benefit or suffer from an increase in the number of consumers buying the same environmental variant. They are related to network as a determinant of a bandwagon effect, whereas its impact on the design of fiscal measure is out of their scope.[3]

Finally, we contribute to the debate on the incentive to relocate manufacturing activities to react to unilateral climate policy, thereby avoiding tax compliance. In a large strand of theoretical research, several arguments are found both in favor and against the possible shift of domestic activities abroad due to unilateral carbon taxes, whereas the empirical literature provides mixed evidence (Petrakis and Xepapadeas, 2003; Ulph and Valentini, 2001; Abe and Zhao, 2005; Ikefuji *et al.*, 2016; Sanna Randaccio *et al.*, 2017). Although we do not introduce an international oligopoly, we observe that firms' profits are unaffected by the N-RQ tax when it is targeted to consumers.

The paper is organized as follows. The model is presented in Section 2. Section 3 characterizes the equilibrium in the case of a relative quality-based tax (RQ tax). Section 4 describes the equilibrium configuration when the tax has two components – quantity and quality (N-RQ tax). Section 5 concludes. We analyze in the Appendix the different effects of the N-RQ tax when firms bear it.

[3]The literature on the drivers of private consumers' decisions has identified a bandwagon effect in green consumption so that the demand for dirtier products can be increased by the fact that many people purchase these products. Symmetrically, the demand for cleaner goods increases with the share of people buying environmentally friendly products. This bandwagon effect may be due to the conspicuous nature of green consumption (see, e.g., Carlsson et al. 2010), conformism (see, e.g., Crutchfield 1955 and Sustein 2003), social norms, or moral constraints (Welsch and Kuhling 2009, Salazar et al. 2013, among others).

2 The model

Consider an uncovered vertically differentiated market with two firms H and L producing two variants of the same good, namely u_H and u_L. Variants are homogeneous in terms of hedonic quality but they are vertically differentiated in terms of polluting emissions. Without loss of generality, variant u_H is assumed to pollute less than variant u_L so that the former (resp. latter) variant will be referred to as high (resp. low) quality variant, with $u_H > u_L$.[4]

Consumers are uniformly distributed in the interval $[0, \beta]$ with density $1/\beta$ and characterized by the intensity of their environmental concern θ. Since the parameter θ is proportional to the willingness to pay (henceforth WTP) for environmental quality, at $\theta = \beta$ the WTP is maximal. Without loss of generality, we set $\beta = 1$. Each consumer is supposed to buy at most one unit of variant which ensures to her the highest utility except if the alternative of no purchase is better. As for production costs, for the sake of simplicity we set them to zero.[5]

Under the assumption that both firms are active in the market, we analyse the following two-stage game. First, firms choose the optimal quality of their variant along the spectrum of the technologically feasible quality, given by the interval $[u_{\min}, \bar{u}]$ where $u_{\min} > 0$ represents the minimal quality required and $\bar{u}$ the highest achievable quality according to the state of the art technology. Second, they compete in prices. Thus, we characterize the market equilibrium configuration in two different scenarios. First we consider the RQ tax and then the N-RQ tax.

3 The RQ tax

First, we consider a scenario where the per-unit tax T is related to the quality gap between variants along the environmental quality ladder, i.e.: $T = t(u_H - u_L)$, where parameter t indicates the tax rate, $t \in (0, 1)$. This gap describes the damage along a *quality dimension*. The cleaner is the green variant relative to the brown variant, the larger the *fiscal punishment*. We consider that it is directly levied on the consumers buying the brown good.

Consumers' preferences are standard, namely, consumers are willing to purchase if and only if they get non-negative utility from buying.

[4] In our model, like in Rodriguez-Ibeas (2007), Garcìa-Gallego and Georgantzís (2009), we follow the traditional approach of vertical differentiation as in Mussa and Rosen (1978) and Gabszewicz and Thisse (1979) so that the variable u_i mirrors the environmental quality i.

[5] Numerical simulations show that our analysis is robust to a convex quality cost $\frac{u_i^2}{2}$ which is fixed in quantity.

However, when buying the dirty product, consumers are faced with the tax T. Formally, the indirect utility from buying good $i = H, L$ is, respectively:

$$U_H = \theta u_H - p_H$$
$$U_L = \theta u_L - p_L - t(u_H - u_L).$$

As a result, the indifferent consumers between buying good L and not buying at all, and between buying good L and good H, are, respectively:

$$\theta_L = \frac{p_L + t\,(u_H - u_L)}{u_L}, \theta_H = \frac{(p_H - p_L - t\,(u_H - u_L))}{u_H - u_L}. \tag{1}$$

Demands for the goods, assuming an uncovered duopoly, are then: $x_L = \theta_H - \theta_L$ and $x_H = 1 - \theta_H$.

As for the firms, the profit of firm $i = H, L$ is

$$\pi_i\,(p_H, p_L) = x_i p_i$$

As usual we solve the game by backward induction. Thus, since firms first define the optimal quality and then prices, we start considering the price stage. Then, we move to the quality stage.

At the price stage, price competition leads to the following second stage equilibrium prices:

$$p_H\,(u_H, u_L) = \frac{u_H(u_H - u_L)\,(t + 2)}{4u_H - u_L},$$
$$p_L\,(u_H, u_L) = \frac{(u_H - u_L)(tu_L - 2tu_H + u_L)}{4u_H - u_L}.$$

Second stage equilibrium profits are then:[6]

$$\pi_H\,(u_H, u_L) = \frac{(2 + t)^2 u_H^2 (u_H - u_L)}{(4u_H - u_L)^2}, \tag{2}$$
$$\pi_L\,(u_H, u_L) = \frac{u_H(u_H - u_L)(u_L + t(-2u_H + u_L))^2}{u_L(4u_H - u_L)^2}. \tag{3}$$

It is worth noting that in the case the relative tax $T = t(u_H - u_L)$ is levied on the brown firm rather than on brown consumers, second stage equilibrium profits, for any quality pair, coincide with the ones

[6] We check that for any (u_H, u_L), second stage equilibrium prices are such that $0 < \theta_L < \theta_H < 1$.

above.[7] This implies that quality competition is independent of the recipient of the tax.[8] Solving for quality competition, we can then write the following.

Lemma 1 *Under an RQ tax, the equilibrium qualities are* $\tilde{u}_H = \overline{u}$ *and* $\tilde{u}_L = \overline{u}\frac{(2-t)+\sqrt{(2+t)(2+25t)}}{7+3t}$.

Proof. See Appendix 6.1. ■

The corresponding equilibrium prices are then:

$$\tilde{p}_H = \frac{\overline{u}}{16}\left[6+3t-\sqrt{(2+t)(2+25t)}\right],$$
$$\tilde{p}_L = \overline{u}\frac{2-t(33+23t)+(5t+1)\sqrt{(2+t)(2+25t)}}{8(7+3t)}.$$

These prices are positive for any admissible value of t. Thus, the equilibrium demands are immediately found as:

$$\tilde{x}_H = \frac{26+13t+\sqrt{(2+t)(2+25t)}}{48},$$
$$\tilde{x}_L = \frac{38+7t-5\sqrt{(2+t)(2+25t)}}{96}.$$

In turn, equilibrium profits write as:

$$\tilde{\pi_H} = \overline{u}\frac{(2+t)^2(7+3t)(5+4t-\sqrt{(2+t)(2+25t)})}{(-26-13t+\sqrt{(2+t)(2+25t)})^2},$$
$$\tilde{\pi_L} = \frac{\overline{u}}{384}\left[4-t(116+131t)+(2+25t)\sqrt{(2+t)(2+25t)}\right]$$

Comparative statics reveal the following. As the tax rate t increases, the environmental quality of the brown good, u_L increases, its quantity, $\tilde{x}_L$, decreases at the benefit of the quantity of the green good, $\tilde{x}_H$, that increases; overall, the total quantity in the market $\tilde{x}_L + \tilde{x}_H$ increases if and only $t > 0.037$. As for the profits, they decrease.

[7] Formally, in this case the indirect utility from buying good $i = H, L$ is $U_i = \theta u_i - p_i$; whereas the profit of the brown and the green firm L and H write, respectively as (ft stands for firm-based tax): $\pi_L^{ft}(p_H, p_L) = x_L^{ft}(p_L - T)$ and $\pi_H^{ft}(p_H, p_L) = x_H^{ft} p_H$. Formal details on price competition are standard and they lead to second-stage equilibrium profits that coincide with (2) and (3). Computations are available upon request from the authors.

[8] Clearly, when the RQ tax is levied on the firm, the equilibrium price of the brown firm is such that $\tilde{p}_L^{ft} - T = \tilde{p}_L$.

To capture the effect of this tax on global emissions, we define pollution damage as:

$$\tilde{E} = \tilde{E}_H + \tilde{E}_L,$$

with $\tilde{E}_i = (u^0 - u_i)\,\tilde{x}_i$, $i = \{H, L\}$ and the parameter u^0 representing the zero emission quality.[9] Note that, by definition, $u^0 \geq \overline{u}$. So, it may happen that the emission-free quality benchmark is not available in the market and thus $u^0 > \overline{u}$.[10] At equilibrium, we find:

$$\tilde{E}_H = (u^0 - \overline{u})\frac{(2+t)(7+3t)}{26 + 13t - \sqrt{(2+t)(2+25t)}},$$

$$\tilde{E}_L = \frac{(38 + 7t - 5\sqrt{(2+t)(2+25t)})u_0 - 4(2 - 11t + \sqrt{(2+t)(2+25t)})\overline{u}}{96},$$

with $\frac{\partial \tilde{E}_H}{\partial t} \geq 0$ and $\frac{\partial \tilde{E}_L}{\partial t} < 0$. Thus, the damage generated by the cleaner firm increases unless its environmental quality is emission-free ($u^0 = \overline{u}$). This quite surprising result is observed since the tax increases the quantity sold in the market by the green producer, for a given environmental quality. Note also that the damage generated by the brown firm decreases: taxation induces an improvement in the environmental quality as well as a reduction of the quantity sold by this firm. Concerning global emissions, direct computations show that

$$\frac{\partial \tilde{E}}{\partial t} \geq 0 \iff t \geq \tilde{t}(u_0, \overline{u})$$

where $\tilde{t}(u_0, \overline{u}) \equiv \frac{-26(3u_0 - 2\overline{u})(u_0 + \overline{u}) + 3(11u_0 + 6\overline{u})\sqrt{2}\sqrt{(3u_0 - 2\overline{u})(u_0 + \overline{u})}}{25(3u_0^2 + u_0\overline{u} - 2\overline{u}^2)}$.

The threshold $\tilde{t}(u_0, \overline{u})$ is positive and increasing in $\overline{u}$.[11] In words, global emissions decrease with the tax for a low level of t, and increase otherwise. Indeed, on the one hand, a *quantity effect* is such that, for high values of t, the overall quantity in the market increases with the tax and, everything else being equal, global emissions too. On the other hand, a *quality effect* is such that the average quality in the market increases with t. As a by-product, for a high value of t ($t \geq \tilde{t}(u_0, \overline{u})$) the net effect of the two drivers turns out to be environment detrimental.

We can summarize these findings as follows:

[9] This function of total emissions resembles the traditional one (see for example Lombardini-Riipinen, 2005), where emission differential are weighted for the quantity sold by firms.

[10] This formulation is quite general as it allows us to consider also the case in which $\overline{u} = u^0$. Although from a theoretical viewpoint, $\overline{u} = u^0$ represents a particular case of our approach, casual observations show that it holds in some sectors. For example, in the automotive sector the electric car is emission-free.

[11] Its maximum is $\tilde{t}(u_0, u_0) = 1$.

Proposition 2 *An RQ-tax is effective in curbing global emissions, if and only if the tax burden is sufficiently low. Otherwise, it turns out to be ineffective. Nonetheless, it hurts both firms whose profits unambiguously decrease.*

4 A novel fiscal design: the N-RQ tax.

We consider now an alternative scenario where the tax is related not only to the *relative quality* of the brown good, but also to the *number of consumers buying* this good. More precisely, the per-unit tax T' is defined here as

$$T' = t\left(u_H - u_L\right)x_L^t.$$

We keep the assumption that it is imposed on consumers.[12]

Formally, we define the indirect utility function from buying the brown variant u_L as follows:

$$U_L\left(\theta\right) = \theta u_L - p_L - T'. \tag{4}$$

The former components, u_L and p_L are in line with the traditional model of vertical differentiation (Mussa and Rosen, 1978). As for the latter, that depends on $x_L^t(p_H, p_L)$, it resembles a sort of network effect as consumers' preferences also depend on what the others purchase. In our approach, however, this element is a proxy for the relevance of the environmental problem generated by dirtier products: it somehow describes the damage along a quantity dimension.

A standard utility function of vertical differentiation is instead assumed for green consumers, namely the indirect utility from buying variant u_H is:

$$U_H(\theta) = \theta u_H - p_H. \tag{5}$$

Denote θ_L^t and θ_H^t the indifferent consumer between buying the low quality variant and not buying at all, and the indifferent consumer between buying variant L and variant H, respectively. Assuming that both firms are active in the market, the demands for the goods are: $x_H^t = 1 - \theta_H^t$ and $x_L^t = \theta_H^t - \theta_L^t$, with $\theta_L^t < \theta_H^t < 1$.[13] The indifferent consumer θ_L^t, is then a function of θ_H^t, and it is given by

$$\theta_L^t(\theta_H^t) = \frac{p_L + t(u_H - u_L)\theta_H^t}{t(u_H - u_L) + u_L} \tag{6}$$

[12] We briefly discuss later on the alterantive case where this tax is borne by the dirty firm and relegate in Appendix 6.3 formal details.

[13] We then verify that, indeed, at equilibrium, these conditions are satisfied, that is, the market is an uncovered duopoly.

This indifferent consumer θ^t_H is found from the following indifferent condition:

$$\theta^t_H u_H - p_H = \theta^t_H u_L - p_L - t(u_H - u_L)\left(\theta^t_H - \frac{p_L + t(u_H - u_L)\theta^t_H}{t(u_H - u_L) + u_L}\right)$$

which is satisfied at

$$\theta^t_H = \frac{(u_L + tu_H - tu_L)\, p_H - p_L u_L}{(u_H - u_L)\,(u_L + tu_H)}. \tag{7}$$

Substituting (7) into (6), we get that:

$$\theta^t_L = \frac{p_L + tp_H}{u_L + tu_H}.$$

Note that the above consumers' maximization problem is solved by assuming rational expectations about the size of the brown market share: when optimally choosing their variant, consumers take the decisions of the others as given and at equilibrium the expected demand of brown consumers coincides with its actual value.

As before, we solve the game by backward induction.

At the price stage, firms maximize the following profits' functions:

$$\pi^t_H\,(p_H, p_L) = x^t_H p_H \text{ and } \pi^t_L\,(p_H, p_L) = x^t_L p_L.$$

Best replies are then:

$$p^t_H\left(p^t_L\right) = \frac{(u_H - u_L)(tu_H + u_L)}{2(t(u_H - u_L) + u_L)} + \frac{p^t_L u_L}{2(t(u_H - u_L) + u_L)}, \tag{8}$$

$$p^t_L\left(p^t_H\right) = \frac{p^t_H u_L}{2u_H}. \tag{9}$$

For future reference, note how the fiscal policy affects $p^t_H\left(p^t_L\right)$: it reduces its slope and it increases its intercept. By solving the system of best replies, we find the pair of candidate equilibrium prices:

$$p^t_H(u_H, u_L) = \frac{(2u_H u_L^2 - 2tu_H^3 - 2u_H^2 u_L + 2tu_H^2 u_L)}{4tu_H u_L - 4u_H u_L + u_L^2 - 4tu_H^2}$$

$$p^t_L(u_H, u_L) = \frac{(u_L^3 - u_H u_L^2 + tu_H u_L^2 - tu_H^2 u_L)}{4tu_H u_L - 4u_H u_L + u_L^2 - 4tu_H^2}$$

as well as demands that we plug into the profit functions.

Next, solving for quality competition, we find the following result.

Lemma 3 *Under an N-RQ tax on consumers, the equilibrium qualities are:* $\tilde{u}_H^t = \bar{u}$ *and* $\tilde{u}_L^t = \frac{2}{7}\bar{u}\left(1 - t + \sqrt{5t + t^2 + 1}\right)$.

Proof. See Appendix 6.2. ■

The equilibrium prices $\tilde{p}_i^t$ and the corresponding market shares $\tilde{x}_i^t$ of firms H and L are, respectively:

$$\tilde{p}_H^t = \frac{1}{4}\bar{u} \text{ and } \tilde{p}_L^t = \frac{1}{28}\bar{u}\left(\sqrt{t^2 + 5t + 1} - t + 1\right),$$
$$\tilde{x}_H^t = \frac{7}{12} \text{ and } \tilde{x}_L^t = \frac{-1 + t + \sqrt{1 + t(5 + t)}}{12t}.$$

The optimal quality $\tilde{u}_L^t$ chosen by the dirty producer and the corresponding price $\tilde{p}_L^t$ increase with the tax, while the equilibrium market share $\tilde{x}_L^t$ decreases. The market share of the cleaner producer $\tilde{x}_H^t$ is instead unaffected by the tax. The rationale for the above findings can be captured as follows. On the one hand, the optimal brown quality increases with the tax. This would enlarge, *ceteris paribus*, the market share of the dirty producer. Still, the corresponding price of the brown variant p_L^t increases with the tax, too. This raise pushes away from the market some low-income consumers, which would have been willing to buy the dirty variant at some lower price $\tilde{p}_L < \tilde{p}_L^t$, but refrain from buying at this high equilibrium price. On the other hand, consumers purchasing the cleaner variant are completely unaffected by the presence of the tax: the tax moves upward the optimal quality of the brown variant and this would induce some consumers buying the green good to switch to the brown alternative, *ceteris paribus*. This switch, however, is refrained by the high price of the brown good. As a result of these two contrasting forces, the equilibrium market share of the green producer does not react to the tax. Not even the equilibrium price $\tilde{p}_H^t$ of the green variant changes with the tax. Although the optimal price of the brown variant increases with this fiscal measure and prices are strategic complements, the quality gap between variants $(\tilde{u}_H^t - \tilde{u}_L^t)$ at equilibrium decreases with t. Since the lower is the quality gap, the fiercer is the price competition, the green firm does not find it optimal to change its equilibrium price, which accordingly does not vary with the tax.

Finally, taxation does not determine any effect on both equilibrium profits that write as:

$$\tilde{\pi}_H^t = \frac{7}{48}\bar{u}, \tag{10}$$
$$\tilde{\pi}_L^t = \frac{1}{48}\bar{u}. \tag{11}$$

We consider this result in the light of the debate on the relocation effects which are possibly induced by a unilateral carbon tax, thereby weakening firms' incentive to comply with abatement measures. It immediately emerges that no penalty is suffered by firms, which accordingly do not find any incentive to relocate.[14] It is worth noticing that this result departs from those which are typically observed when a traditional carbon tax is introduced in a market, as proved in the previous section. In that case, relocation incentives emerge as a means to avoid reduction in equilibrium profits.

As for the effect of this tax on global emissions, at equilibrium total damage writes:

$$\tilde{E}^t = \frac{1}{12}\frac{u^0(\sqrt{5t+t^2+1}+8t-1)-9\bar{u}t}{t}, \tag{12}$$

with $\frac{\partial \tilde{E}^t}{\partial t} < 0$ given that the average environmental quality in the market increases, while the brown production as well as total production decrease with t.

We gather our findings as follows.

Proposition 4 *An N-RQ tax on consumers unambiguously decreases global emissions without reducing firms' equilibrium profits.*

Thus, the effects determined by the two fiscal measures – RQ and N-RQ taxes –are different. As far as the environmental effectiveness, only the N-RQ tax unambiguously reduces emissions, whereas the RQ instrument is effective in curbing emissions for a low level of taxation. When considering the effect of taxes on firms' profits, we observe that firms are unaffected by an N-RQ tax while the dirtier producer being penalized by the RQ tax.

A last remark is in order. The effects of this N-RQ tax are not independent of the fiscal recipient. For this to be clear, let us assume that the $N-RQ$ per-unit tax $T = t\,(u_H - u_L)\,x_L^{ft}$ is imposed on the polluting firm (the superscript ft stands for firm-based tax), whereas consumers do not pay taxes when buying brown products. Thus, the profit of firm L writes as

$$\pi_L^{ft}\,(p_H, p_L) = x_L^{ft}\,(p_L - T)\,,$$

whereas the profit of the green firm H is still $\pi_H^{ft}\,(p_H, p_L) = x_H^{ft} p_H$. As we show in Appendix 6.3 this tax is environment enhancing but

[14] Indeed, formally, the equilibrium profits defined in (10) and (11) correspond to those under the baseline scenario à la Choi and Shin (1992), in the absence of policy intervention.

profit detrimental: equilibrium profits of firm Ldecreases with t which, in turn, may induce relocation and carbon leakage effects. When the fiscal penalty is directly imposed on the dirty firm, it tends to increase its price to weaken the effect of the tax on the net price. Nonetheless, this raise in price generates a reduction in the corresponding demand, with a negative impact on the resulting profits.

This finding opens the door to some considerations on the role of a tax recipient. A commonly shared view is that when firms are taxes, they tend to transfer on consumers, via prices, the tax burden which they directly bear. Accordingly, the equilibrium confuguration of the market does not change with the recipient of the tax. This finding does not hold when an N-RQ tax is adopted: in this case, only a tax on consumers is effective in curbing emissions while preserving firms' profits. Under an N-RQ tax on the dirty firm, the well-know trade-off between environmental protection and industry's competitiveness is observed.

5 Conclusions

In the lively debate on the opportunity of using carbon taxes, economic literature has usually analyzed the trade-off between losses and benefits deriving from an Environmental Fiscal Reform (EFR). Supporters of carbon taxes argue that they could incentivize green behavior and spread environmentally friendly habits among producers and consumers. Further, since these taxes are based on the so-called polluter pays principle such that "whoever is responsible for damage to the environment should bear the costs associated with it" (Taking Action, The United Nations Environmental Programme), they comply with efficiency and equity requirements. However, the opponents point out that unilateral climate measures may hurt firms' competitiveness and possibly firms' relocation.

In this paper, we have embraced a different view. We have shown that a tax on consumers, if properly designed, effectively reduces emissions and does not provide firms with relocation incentives.

6 Appendix

6.1 Proof Lemma 1

First, we find that $\frac{\partial}{\partial u_H}\pi_H(u_H, u_L; t) > 0$, always. The optimal choice of firm H is then $\tilde{u}_H = \overline{u}$.

As for firm L, given $u_H = \overline{u}$ the first derivative of π_L wrt u_L is positive iff:

$$16t^2u_H^3+(8tu_H^2-4t^2u_H^2-8t(1+t)u_H^2)u_L+(-14tu_H-6t^2u_H-4(1+t)u_H+2t(1+t)u_H)u_L^2$$
$$+(7(1+t)+3t(1+t))u_L^3 > 0.$$

This polynomial has three u_L-roots: one is negative, the other two roots are in the interval $(0,1)$:

$$u_{L1} = \frac{2tu_H}{1+t} < u_{L2} = u_H \frac{(2-t)+\sqrt{(2+t)(2+25t)}}{7+3t}.$$

For $u_L \in (u_{min}, u_{L1})$ the profit decreases with u_L, for $u_L \in (uL1, uL2)$ the profit increases with u_L, finally for $u_L > u_{L2}$ the profit decreases with u_L. We conclude that u_{L2} is the maximum. Note that we are implicitly assuming that, reasonably, the value of Π_L computed in $u_L = u_{Lmin} < u_{L1}$ is lower than Π_L in $u_L = u_{L2}$, that is $u_{Lmin} < u_{L1}$ is sufficiently high.

6.2 Proof Lemma 3

First, we find that $\frac{\partial}{\partial u_H}\pi_H(u_H, u_L; t) > 0$, always. The optimal choice of firm H is then $\tilde{u}_H = \overline{u}$. Given $u_H = \overline{u}$, we obtain the optimal value of the brown variant from standard maximization of $\pi_L(\overline{u}, u_L)$ wrt u_L. Formally, the first derivative of π_L wrt u_L is positive iff:

$$8t^2u_H^5uL + u_H^2(12tu_H^2 - 12t^2u_H^2)u_L^2 + u_H^2(4u_H - 22tu_H + 4t^2u_H)u_L^3 + (-7+7t)u_H^2u_L^4 > 0$$

This polynomial has 4 u_L-roots. Only one is strictly positive, that is $\frac{\tilde{u_L^t}}{\overline{u}} = \frac{2}{7}\left(1 - t + \sqrt{5t+t^2+1}\right) \in (4/7, 1)$. Indeed, in $u_L = (4/7)u_H$ the sign of $\frac{\partial}{\partial u_L}\pi_L(\overline{u}, u_L; t)$ is positive, that is the profit is still increasing and, in turn, the optimal quality $\frac{\tilde{u_L^t}}{\overline{u}} > 4/7$. It holds that $\frac{\tilde{u_L^t}}{\overline{u}} = 4/7$ at t=0 as in Choin and Shin (1992).

6.3 N-RQ tax imposed on the brown firm

For the sake of comparison, we next analyze the scenario where the tax is directly levied on the brown producer. Consumers' preferences are standard. Formally, the indirect utility from buying good i is

$$U_i = \theta u_i - p_i.$$

As a result, the indifferent consumers between buying good L and not buying at all, and between buying good L and good H, are, respectively:[15]

$$\theta_L^{ft} = \frac{p_L}{u_L}, \theta_H^{ft} = \frac{p_H - p_L}{u_H - u_L}. \tag{13}$$

Demands for the goods, assuming an uncovered duopoly, are then: $x_L^{ft} = \theta_H^{ft} - \theta_L^{ft}$ and $x_H^{ft} = 1 - \theta_H^{ft}$.

[15] Superscript ft stands for firm-based tax.

Given the $N-RQ$ per-unit tax $T(p_H, p_L, u_H, u_L; t) = t\,(u_H - u_L)\,x_L^{ft}$, the profit of the brown firm L writes as $\pi_L^{ft}(p_H, p_L) = x_L^{ft}\,(p_L - T(p_H, p_L, u_H, u_L; t))$, whereas profit of the green firm H is $\pi_H^{ft}(p_H, p_L) = x_H^{ft} p_H$.

As usual, we solve the game by backward induction. Price competition leads to the following best replies:

$$p_H^{ft}\left(p_L^{ft}\right) = \frac{(u_H - u_L)}{2} + \frac{1}{2} p_L^{ft}, \tag{14}$$

$$p_L^{ft}\left(p_H^{ft}\right) = \frac{p_H^{ft} u_L (2tu_H + u_L)}{2u_H(tu_H + u_L)}. \tag{15}$$

It is worth stressing that when considering an N-RQ tax, price competition develops in different ways in the two scenarios (consumer-based tax versus firm-based tax). Indeed, looking at the price competition reaction functions defined in 8, 9, 14 and 15, we can note the following.

- In the consumer-based scenario, the fiscal policy increases the intercept and reduces the slope of $p_H^t(p_L)$, whereas it does not affect $p_L^t(p_H)$; in the firm-based scenario, instead, the fiscal policy does not affect $p_H^{ft}(p_L)$, whereas it increases the slope of $p_L^{ft}(p_H)$.
- The intercept of 8 is larger than the intercept of 14, whereas the slope of 9 is larger than the slope of 15: in the consumer-based scenario the price of the brown variant is less sensitive to changes in the price of the green variant as compared with the firm-based scenario.

Second stage prices are then:

$$p_H^{ft}(u_H, u_L; t) = \frac{2u_H (u_H - u_L)(u_L + tu_H)}{u_L (4u_H - u_L) + 2tu_H (2u_H - u_L)},$$

$$p_L^{ft}(u_H, u_L; t) = \frac{u_L (u_H - u_L)(u_L + 2tu_H)}{u_L (4u_H - u_L) + 2tu_H (2u_H - u_L)}.$$

with the corresponding second stage demands and profits being:

$$x_L^{ft}(u_H, u_L; t) = u_H \frac{u_L}{u_L (4u_H - u_L) + 2tu_H (2u_H - u_L)},$$

$$x_H^{ft}(u_H, u_L; t) = 2u_H \frac{u_L + tu_H}{u_L (4u_H - u_L) + 2tu_H (2u_H - u_L)}, \tag{16}$$

$$\pi_L^{ft}(u_H, u_L; t) = \frac{u_L^2 (u_H - u_L)(u_L + tu_H) u_H}{(-u_L^2 + 4u_H u_L + 4tu_H^2 - 2tu_H u_L)^2}, \tag{17}$$

$$\pi_H^{ft}(u_H, u_L; t) = \frac{4^2 u_H^2 (u_H - u_L)(u_L + tu_H)^2}{(-u_L^2 + 4u_H u_L + 4tu_H^2 - 2tu_H u_L)^2}. \tag{18}$$

As for quality competition, first, we find that $\frac{\partial}{\partial u_H}\pi_H^{ft}(u_H, u_L; t) > 0$, always. The optimal choice of firm H is then $u_H^{ft} = \overline{u}$. As for firm L, π_L^{ft} is concave in u_L. The first derivative is: $\frac{\partial}{\partial u_L}\pi_L^{ft}(u_H, u_L; t) > 0 \iff (3t-7)u_L^3 + 2u_H(-10t+t^2+2)u_L^2 - 12tu_H^2(t-1)u_L + 8t^2u_H^3 > 0$. Set $\frac{u_L}{u_H} = Q \in (0,1)$, the sign of the derivative is as the sign of $f(Q,t)$:

$$f(Q,t) = (3t-7)Q^3 + 2Q^2\left(-10t+t^2+2\right) - 12tQ(t-1) + 8t^2. \quad (19)$$

Given the concavity of π_L^{ft} wrt u_L and, in turn, wrt to Q, and given that $f\left(\frac{4}{7}, t\right) > 0$ and $f(0.691, t) < 0$, we can state that there exists a $Q^{ft}(t) = \frac{\tilde{u}_L^{ft}}{\overline{u}} \in \left(\frac{4}{7}, 0.691\right)$ such that $\frac{\partial}{\partial u_L}\pi_L^{ft}(u_H, u_L; t) > 0$ for $Q < Q^{ft}(t)$, $\frac{\partial}{\partial u_L}\pi_L^{ft}(u_H, u_L; t) = 0$ for $Q = Q^{ft}(t)$ and $\frac{\partial}{\partial u_L}\pi_L^{ft}(u_H, u_L; t) < 0$ for $Q > Q^{ft}(t)$. The equilibrium qualities are then $u_H^{ft} = \overline{u}$ and $u_L^{ft} = \tilde{u}_L^{ft}$ such $Q^{ft}(t) = \frac{\tilde{u}_L^{ft}}{\overline{u}} \in \left(\frac{4}{7}, 0.691\right)$. Finally, global emissions are computed as:

$$\widetilde{E}^{ft} = (u^0 - \overline{u})2\overline{u}\frac{\tilde{u}_L^{ft} + t\overline{u}}{\tilde{u}_L^{ft}\left(4\overline{u} - \tilde{u}_L^{ft}\right) + 2t\overline{u}\left(2\overline{u} - \tilde{u}_L^{ft}\right)} \quad (20)$$
$$+(u^0 - \tilde{u}_L^{ft})\overline{u}\frac{\tilde{u}_L^{ft}}{\tilde{u}_L^{ft}\left(4\overline{u} - \tilde{u}_L^{ft}\right) + 2t\overline{u}\left(2\overline{u} - \tilde{u}_L^{ft}\right)}.$$

Numerical simulations show that, as t increases, $Q^{ft}(t)$ increases, x_L^{ft} decreases, x_H^{ft} increases, total quantity and global emissions decrease, π_L^{ft} decreases and π_H^{ft} increases. Comparing this equilibrium configuration with the scenario where the $N - RQ$ tax is imposed on consumers, we also find the following.

- $Q^{ft}(t) = \frac{\tilde{u}_L(t)}{\overline{u}} < \frac{\tilde{u}_L^t}{\overline{u}}$, that is the average environmental quality in the market is higher in the consumer-based rather than in the tax-based scenario. Indeed, it can be shown that the sign of (19), computed in $\frac{\tilde{u}_L^t}{\overline{u}}$, is negative for any $t > 0$.

- As for global emissions, numerical simulations show that the comparison depends on the quality gap $\frac{\overline{u}}{u^0}$.

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