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Green Consumers and the Transition to Sustainable Production*

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Abstract

We investigate the interaction between consumers' environmental concern, environmental corporate social responsibility (ECSR), and environmental regulations during the transition towards sustainable production. We study an economy in which a subpopulation of consumers is sensitive to environmental issues. In this setting, we analyse the steady-state equilibrium in a framework *à la* Droste et al. (2002), where firms compete in quantities and decide whether or not to engage in ECSR activities, which ultimately reduce the impact of production on the environment. We find that the variation of social welfare with the increase of ECSR firms is U-shaped, driven by the variation in consumer surplus, while environmental damage is minimised when all firms adopt ECSR practices. Therefore, the short-run social incentives to pursue a transition towards sustainable production are scarce. In contrast, there exists a private incentive to internalise emissions and to proliferate ECSR firms, as profits increase with the proportion of ECSR firms.

JEL Codes: C73, H23, L13, L21, M14

Keywords: Mixed oligopoly markets, emission reduction investment, evolutionary dynamics.

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1 Introduction

The growing environmental concerns of consumers are undoubtedly having a significant impact on corporate decision making and environmental policy implementation. A large body of empirical evidence shows that consumers are increasingly prioritising green products and practices in their purchasing decisions.

This is confirmed by a large number of studies.[1] To name a few, Hidrue et al. (2011) show that a proportion of consumers are willing to pay a price premium for electric vehicles. Krishnamurthy and Kriström (2015) find that some consumers are willing to pay more for green energy. Naderi and Van Steenburg (2018) identify a significant increase in environmental concern among millennials, attributed to a combination of selfless altruism, frugality, risk aversion and time orientation that motivates them to engage in environmental activities. Through surveys and market analysis, they show how environmental concerns have permeated various sectors, leading to the proliferation of eco-friendly products and an expansion of the market for green products. More recently, Kesselring (2023) finds that willingness to pay for a product's energy efficiency emerges when energy consumption is associated with other observed attributes that consumers associate with energy savings. In response to this increase in demand for green products, many firms have started to implement green production and marketing strategies to meet the preferences of environmentally conscious consumers, which has become a key development in modern business (Nekmahmud and Fekete-Farkas, 2020, among others).

While much of the literature on environmental regulation already acknowledges the presence of environmentally conscious consumers,[2] their proliferation in the population and its implications for business and policy choices have not yet been thoroughly investigated. This is the focus of the present paper.

We study how consumers' environmental concerns interact with environmental corporate social responsibility (ECSR) and environmental regulation in the transition to sustainable production. We model consumers' environmental concern as the share of environmentally aware consumers in the population and their sensitivity to environmental issues. A firm could choose

[1] See White et al. (2019) for a review of the literature.

[2] The assumption of green consumers is common in the theoretical economic literature that is interested in determining their effects on product demand of environmental policy interventions, see for instance, Moraga-González and Padrón-Fumero (2002), Bansal and Gangopadhyay (2003) and Conrad (2005), among many others.

to ignore its environmental impact and pursue standard profit maximisation. Alternatively, a firm may adopt ECSR practices; in this case, it takes into account its environmental impact in its production decisions.

We analyse the steady state industry configuration that emerges by the strategic choice of a firm's objective of business (profit maximiser or ECSR) in an evolutionary setting. The transition from polluting to sustainable production occurs as the share of ECSR firms increases until all firms internalise their emissions.

Our results show that the transition to a production style that voluntarily reduces its emission reduction is hard to implement from a policy perspective. As the population of environmentally conscious consumers increases, the proportion of firms that willingly reduce their emissions also increases. This brings about a U-shaped change in the level of social welfare, which is driven at the margin by consumer surplus. This result is explained by the fact that when the market exhibits a similar proportion of firms of different types, the proportion is also similar in the differentiation of goods, and thus firms overall gain higher market power, which reduces consumers' benefits.

Since the transition to a more sustainable production reaches a minimum level of social welfare in the process, this somehow diminishes the social incentives to push for it, at least in the short run. One might argue that since political mandates are short-term, the government has little incentive to pursue it. In contrast, the transition brings about a slight increase in profits. Thus, the private incentives may drive the transition, provided that environmental regulatory policy is in place to ensure incentives to abate polluting emissions.

The remainder of the paper is organised as follows. Section 2 briefly surveys the relevant literature. Section 3 develops the framework, while Section 4 outlines the equilibrium and its properties. Specifically, Section 4.1 studies the static oligopoly setting, in which firms take their competitors' type and their own as given, while Section 4.2 analyses the long-run industry configuration in an evolutionary duopoly setting where firms endogenously set their own type. Welfare analysis is developed in Section 5 , while Section 6 concludes.

2 Literature

The present paper is related to three strands of economic literature: the literature on strategic ECSR, the literature on environmental regulation in strategically competitive markets and the literature on endogenous market structure with environmentally and socially concerned firms.

About the former, a common approach to understanding ECSR behaviour involves modelling a firm's objective function, which incorporates components such as consumer surplus, the effects of polluting emissions, and profits (Lambertini and Tampieri, 2015, Lambertini et al., 2016, Fukuda and Ouchida, 2020 and Iannucci and Tampieri, 2023, Xu and Lee, 2022, Xu et al., 2022a, among others). In this strand of the literature, ECSR practices can also be interpreted as managerial delegation, where the manager's contract is based on the level of emissions produced by the firm. This delegation type is, of course, relevant when environmental regulatory measures are implemented within the industry. Studies exploring this direction include Lee and Park (2019), Poyago-Theotoky and Yong (2019), Buccella et al. (2022) and Buccella et al. (2023a), among others.

An alternative way to incorporate ECSR behaviour is to acknowledge the presence of green consumers in the economy. The concept is that environmentally conscious consumers place a higher value on goods produced with minimal environmental impact, thus they are willing to pay a premium for such products. Consequently, ECSR firms have a strategic incentive to reduce their production emissions to attract these consumers. This approach has been adopted, for instance, by Manasakis et al. (2013), Manasakis et al. (2014), Liu et al. (2015), Xu and Lee (2023) and Fang and Zhao (2023).

This paper is primarily related to these latter contributions by incorporating environmentally conscious consumers into the analysis. The central focus of this study is to examine how the size of the proportion of green consumers, as well as their level of sensitivity to environmental issues, influences firms' decision-making regarding business objectives and environmental policy design. A similar approach with different types of consumers has been employed by Ambec and De Donder (2022), although they do not consider firms' strategic interaction.

The paper is also linked to the literature on environmental regulation in oligopolies. This strand has largely developed in different directions, some of which are mentioned above and include the presence of ECSR firms. Most parts of the literature have focused on static models in which the regulatory intervention takes the shape of a tax on emissions (see, among others, Poyago-Theotoky, 2007, Ouchida and Goto, 2016, Mc Donald and Poyago-Theotoky, 2017, Lambertini et al., 2017, Buccella et al., 2021, Xu et al., 2022b and Xu and Lee, 2022). In dynamic frameworks, Benchekroun and Chaudhuri (2011) find that the introduction of a Markovian tax may spur collusion, with negative effects on welfare. Other contributions investigated the introduction of an emissions trading system in evolutionary settings and perfect competition (Antoci et al., 2019, Antoci et al., 2020 and Antoci et al., 2021, among others). Related to many of these contributions, we study the introduction of a tax on emissions and how this policy interacts with consumers' and firms' environmental concern.

Together with the above-mentioned contributions in the literature on strategic ECSR and its interaction with an emission tax, the paper is also related to the literature on the endogenous market structure in mixed oligopolies with environmentally concerned firms. This topic has been studied by Lambertini and Tampieri (2015) and Lambertini et al. (2020) in static settings. In evolutionary frameworks, it has been analysed by Kopel et al. (2014), Kopel and Lamantia (2018), Iannucci and Tampieri (2023) and Buccella et al. (2023b). The analysis of an evolutionary setting is relevant since it allows us to study the long-run market configuration in a mixed market.

This paper is mainly related to Iannucci and Tampieri (2023) and Buccella et al. (2023b). Both studies employ an evolutionary framework featuring profit-seeking and environmentally conscious firms, along with an emission tax. Iannucci and Tampieri (2023) focus on an evolutionary oligopoly to assess competitive pressures by increasing the number of firms in the market, treating the emission tax as exogenous. In contrast, Buccella et al. (2023b) consider optimal taxation under fixed or optimal rules. Both studies advocate for the long-term coexistence of both types of firms. Both Iannucci and Tampieri (2023) and Buccella et al. (2023b) assume away the presence of environmentally concerned consumers. The incentive to engage in ECSR activities is exclusively due to a strategic advantage among competitors in the presence of a regulatory measure.

Similar to these models, our study adopts an evolutionary framework and treats taxation as exogenously determined, similar to Iannucci and Tampieri (2023). The main innovation lies in integrating a portion of environmentally conscious consumers into this framework: the impact of the proliferation of these consumers in the steady state and their sensitivity to environmental issues outcome is the very scope of the present paper.

3 The model

We analyse an industry composed of $N \geqslant 2$ firms that produce a unique good and compete in quantities. Of these N firms, $N - m \in \{0, 1, 2, \ldots, N\}$ are profit-seeking (PS) and m are environmentally socially concerned (ECSR). A firm's type is indexed by $k \in \{P, E\}$, where a generic PS and ECSR firm and its product x are denoted by P and E, respectively.

The industry serves a population of consumers of measure normalised to one. This population is composed of two subpopulations of $g \in (0, 1)$ "green" consumers and $1 - g$ "brown" consumers, indexed by $\omega \in \{g, b\}$. Following Häckner (2000), a generic consumer ω's utility and budget constraint are given by:

$$U_\omega = a\left(\sum_{P=1}^{N-m} x_P + \sum_{E=1}^{m} x_E\right) + \mathbf{1}_{\{\omega=g\}}\alpha\theta\left(\sum_{E=1}^{m} x_E\right) - \frac{1}{2}\left(\sum_{P=1}^{N-m} x_P^2 + \sum_{E=1}^{m} x_E^2 + \sum_{j\neq P} x_j x_P + \sum_{i\neq E} x_i x_E - \gamma \sum_{P\neq E} x_P x_E\right) + c_0, \tag{1}$$

and

$$I = \sum_{P=1}^{N-m} p_P x_P + \sum_{E=1}^{m} p_E x_E + c_0. \tag{2}$$

In (1) and (2), products of PS firms different from P are labelled as j, while products of ECSR firms different from E are labelled as i. Parameter c_0 represents the composite good, whose price is taken as the numeraire and thus normalised to one. Parameter $\gamma \in [-1, 1]$ represents the degree of substitutability or complementarity among goods. In what follows we assume $\gamma = 1$: this implies that we assume away horizontal differentiation, so that goods are perfectly substitutes.

However, we maintain vertical differentiation. In particular, while the willingness to pay $a > 0$ is the same between green and brown consumers, the former are happy to pay an extra $\alpha\theta$ for each unit purchased from an ECSR firm. In (1), this is represented by the indicator function

$\mathbf{1}_{\{\omega=g\}}$, which takes value 1 if $\omega = g$ and 0 otherwise.

In particular, following Xu and Lee (2023), $\alpha \in (0,1)$ represents the green consumer's increase in the willingness to pay for green products, while $\theta \in (0,1)$ represents the ECSR sensitivity to abate its own polluting emissions (see the section later for details).[3]

Utility maximisation yields the following inverse demand for the good produced by a firm of type k and consumed by consumer ω:

$$p_{k\omega} = a + \mathbf{1}_{\{k=E,\omega=g\}}\alpha\theta - \left(\sum_{P=1}^{N-m} x_P + \sum_{E=1}^{m} x_E\right), \tag{3}$$

where $\mathbf{1}_{\{k=E,\omega=g\}}$ is an indicator function taking values of 1 if the firm is of type ECSR and the consumer is of type G.

We assume that ECSR firms are capable of discriminating prices by groups. For example, they may differentiate prices based on the type of consumers residing in a specific location. In particular, ECSR firms may obtain information (e.g., through market surveys) on the average environmental awareness of the representative consumer in a certain region, and adjust their product prices accordingly. In contrast, PS firms face the same inverse demand, regardless of the consumer's type.

Firms are subject to emission taxation, creating an incentive for them to invest in abating emissions and thereby reduce the tax burden. We define the emissions of each firm as output minus abatement investments ($e = x - z$). Specifically, we assume the use of *end-of-pipe* emission reduction technology which, by definition, aids in reducing emissions of pollutants into the atmosphere but does not have the capability to eliminate environmental damage.

For each firm $k \in \{P, E\}$ serving a consumer ω, profits are given by:

$$\pi_{k\omega} = (p_{k\omega} - c)\, q_k - \frac{z_k^2}{2} - e_k\tau, \tag{4}$$

In, (4), $c > 0$ represents the unit production cost, z_k denotes investment in emissions abatement, and τ is the tax unit on emissions. For each firm k, overall profits are:

$$\Pi_k = g\pi_{kg} + (1-g)\pi_{kb}. \tag{5}$$

[3] As highlighted by Xu and Lee (2023), $\alpha \in (0,1)$ ensures that the equilibrium outcomes are positive.

Note that the distinction between π_{kg} and π_{kb} is, in fact, relevant only for ECSR firms, as the demand for PS products reflects the same willingness to pay from both G and B consumers.

In their maximisation process, however, an ECSR firm E maximises its profits by also internalising its share of emissions. The objective function of each firm E is thus:

$$O_E = \pi_E - \theta e_E, \tag{6}$$

where $\theta \in (0, 1)$ denotes the proportion of emissions that are voluntarily internalised by an ECSR firm.

4 Results

4.1 Static oligopoly

In this section, each firm of the industry takes its own type and that of the competitors as given. The equilibrium is static: firms simultaneously set their quantities and their investment in emissions reduction technology based on their objective function.

Each firm P maximises overall profits with respect to quantities and investment in emission reduction technology:

$$\max_{x_P, z_P} \Pi_P. \tag{7}$$

In contrast, each firm E maximises its objective function, i.e.,

$$\max_{x_E, z_E} O_P. \tag{8}$$

To ease the exposition, in what follows we set $\mu = a - c$, where μ represents market size. The first order conditions of (7) and (8) are, respectively,

$$\frac{\partial \Pi_P}{\partial x_P} = \mu - \tau - \sum_{j \neq P}^{N-m-1} x_j - \sum_{E}^{m} x_E - 2x_P = 0, \tag{9}$$

$$\frac{\partial \Pi_P}{\partial z_P} = \tau - z_P = 0, \tag{10}$$

$$\frac{\partial O_E}{\partial x_E} = \mu - \tau - \sum_{j}^{N-m} x_j - \sum_{i \neq E}^{m-1} x_i - 2x_P - \theta\left(1 - g\alpha\right) = 0, \tag{11}$$

$$\frac{\partial O_E}{\partial z_E} = \tau + \theta - z_E = 0. \tag{12}$$

Invoking symmetry among firms of the same type, we obtain the elements of market equilibrium.

Proposition 1 *Equilibrium quantities and investments in emission reduction of P and E firms are, respectively,*

$$x_P^* = \frac{\mu - \tau + \theta m\left(1 - \alpha g\right)}{N+1},$$
$$x_E^* = \frac{\mu - \tau - \theta\left[\left(1 - \alpha g\right)\left(N - m - 1\right)\right]}{N+1},$$
$$z_P^* = \tau,$$
$$z_E^* = \theta + \tau.$$

A quick look at Proposition 1 shows that both quantities increase with market size and decrease with the unit tax. Additionally, the equilibrium quantities of a PS firm increase with the share of emissions that ECSR competitors are willing to internalise and with the number of ECSR firms in the industry, implying fewer competitors selling the same homogeneous product, thereby enhancing their market power. However, the increase in quantities of PS firms due to ECSR internalisation decreases with green consumers' sensitivity to environmental issues and their share in the population. This seems natural, considering that both α and g somewhat increase the demand for ECSR firms.

Intuitively, this effect is reversed for ECSR firms: their quantities decrease with emission internalisation, which has the same effect of higher production costs. This effect increases with the number of competitors of a different type but decreases with the share of green consumers and their sensitivity to environmental concerns.

The following condition on the tax on emissions ensures interior solutions, given by positive quantities and emissions in the industry.

Corollary 1 *For every $m \in \{0, 1, 2, ..., N\}$, both types of firms exhibit positive equilibrium quan-*

tities and emissions for $\tau \leqslant \overline{\tau}$, where

$$\overline{\tau} \equiv \min\left\{\mu - \theta(N-1)(1-\alpha g), \frac{\mu + \theta(N+1)(2-\alpha g)}{N+2}\right\}.$$

Proof. In Appendix.

The restrictions on the existence of interior solutions based on the unit tax are intuitive: a very high tax on emissions would prevent any positive emission level, which is not observed in the real world. Additionally, it would make production too costly by curbing it until the point at which it is profitable not to produce at all. Therefore, in the following, we assume that

Assumption 1 *Let $\tau \leqslant \overline{\tau}$.*

4.2 Evolutionary duopoly

In this section we consider an evolutionary duopoly setting in which firms choose their type between PS and ECSR based on expected profits. The framework is based on Droste et al. (2002).

We assume continuous time. There is a large number of firms and, at each time period t, a fraction $f \in [0,1]$ of the population is of the type PS, while a fraction $1-f$ is of the ECSR type. In every t, $N = 2$ firms are drawn from the population, forming a duopoly. Firms initially make a simultaneous decision on whether to adopt an ECSR or PS statute by comparing the expected profits associated with the two objectives. Subsequently, they determine their output and emission reduction technology to maximise the selected objective function.

We call $\pi^*_{kk'}$ as the profits of firm $k \in \{P, E\}$ when matched with firm $k' \in \{P, E\}$. In practical terms, random matching implies that the duopoly can be formed between two PS firms, two ECSR firms, or a mix of both. If firm k is of type P, it earns profits π^*_{PP} when matched with another PS type and profits π^*_{PE} when matched with an ECSR type. Similarly, if firm k is of type E, it earns profits π^*_{EP} or π^*_{EE} when matched with a competitor of type PS or ECSR, respectively. Using the results from Proposition 1 when $N = 2$ and $m = 0$ (matching between two PS), $m = 1$ (mixed match), or $m = 2$ (matching between two ECSRs), the optimal profits

Firm 2

Firm 1	*PS*	*ECSR*
PS	π^*_{PP}, π^*_{PP}	π^*_{PE}, π^*_{EP}
ECSR	π^*_{EP}, π^*_{PE}	π^*_{EE}, π^*_{EE}

Table 1
The stage game

for each market composition are:

$$\begin{aligned}
\pi^*_{PP} &= \frac{1}{18}\left(2\mu^2 + 11\tau^2 - 4\mu\tau\right), \\
\pi^*_{PE} &= \frac{1}{18}\left[2(\alpha(-g)\theta + \theta + \mu)^2 + 4\theta\tau(\alpha g - 1) + 11\tau^2 - 4\mu\tau\right], \\
\pi^*_{EP} &= \frac{1}{18}\left[\theta^2\left(8\alpha^2 g^2 - 16\alpha g + 17\right) + 8\theta\mu(\alpha g - 1) + 2\theta\tau(13 - 4\alpha g) + 2\mu^2 + 11\tau^2 - 4\mu\tau\right], \\
\pi^*_{EE} &= \frac{1}{18}\left[\theta^2(2\alpha g(\alpha g - 2) + 11) + 4\theta\mu(\alpha g - 1) + \tau(\theta(22 - 4\alpha g) - 4\mu) + 2\mu^2 + 11\tau^2\right].
\end{aligned}$$

Given the share of population at time t, each firm (either PS or ECSR) is randomly matched with a competitor, where the probability of being paired with a type ECSR competitor is $f(t)$ and with a type PS competitor is $1 - f(t)$. The probability of encountering a type ECSR competitor $f(t)$ is equivalent to the proportion of firms adopting the ECSR strategy in the population at time t. Likewise, the probability of encountering a type PS competitor $1 - f(t)$ corresponds to the proportion of PS-type firms in the population. Whenever the population of firms is sufficiently large, the law of large numbers allows us to consider expected profits as a close approximation to realised profits (Weibull, 1995, p.71-72).

Table 1 illustrates the strategic interactions between two firms engaged in a duopoly, considering their respective types. At each time period t, the expected profits for a firm opting for a PS and ECSR strategy are, respectively,

$$\begin{aligned}
\mathbb{E}\left[\pi^*_P(f)\right] &= f\pi^*_{PE} + (1-f)\pi^*_{PP}, \\
\mathbb{E}\left[\pi^*_E(f)\right] &= f\pi^*_{EE} + (1-f)\pi^*_{EP},
\end{aligned} \tag{13}$$

where we omit the time argument for brevity. The fluctuation in the population of a specific type of firm depends on the comparison of expected profits outlined in Equation (13). This is governed by the following replicator dynamics (Weibull, 1995; Antoci et al., 2021; Tang et al., 2021, among others):

$$\dot{f} = f(1-f)[\mathbb{E}(\pi_E^*(f)) - \mathbb{E}(\pi_P^*(f))]. \tag{14}$$

We denote f^* as a stable steady state. According to (13), the industry is composed only by PS firms ($f^* = 0$) if $\mathbb{E}\pi_P^*(f) > \mathbb{E}\pi_E^*(f)$ for every f. Whenever the population of firms is composed only of PS firms, $\mathbb{E}\pi_P^*(f) > \mathbb{E}\pi_E^*(f)$ amounts to $\pi_{PP}^* > \pi_{EP}^*$. We will refer to this as the *PS industry configuration*. On the other hand, the industry is composed only of ECSR firms (*ECSR industry configuration*, $f^* = 1$) if the ECSR strategy is dominant, i.e., for $\mathbb{E}\pi_P^*(f) < \mathbb{E}\pi_E^*(f)$ for every f. Again, when $f^* = 1$, this amounts to $\pi_{EE}^* > \pi_{PE}^*$. Finally, the industry composition is mixed, implying $f^* \in (0,1)$, if $\mathbb{E}\pi_P^*(f) = \mathbb{E}\pi_E^*(f)$. This will be called the *Mixed industry configuration*.

A preliminary result shows the features of the demand that allow for an ECSR configuration.

Lemma 1 *An ECSR industry configuration may emerge only if $\alpha g > \frac{1}{4}$ and $\mu > \widehat{\mu}$, where*

$$\widehat{\mu} \equiv \max\left\{\frac{\theta(4-\alpha g)(5-4\alpha g)}{4\alpha g - 1}, \frac{\theta}{6}\left(23 + 8\alpha^2 g^2 - 34\alpha g\right)\right\}.$$

Proof. In Appendix.

Lemma 1 states that an industry composed of only ECSR firms emerges if and only if the willingness to pay of G consumers or their proportion in the overall population is sufficiently high. In addition, the market size must be large enough. Since this industry composition is empirically relevant, as well as the diffusion of environmental concern among consumers, in what follows we make the following assumption based on Lemma 1.

Assumption 2 *Let $\alpha g > \frac{1}{4}$ and $\mu > \widehat{\mu}$.*

We are now in a position to study the emergence of the steady state equilibria. Inequality $\pi_{EE}^* > \pi_{PE}^*$ can be written as

$$\pi_{EE}^* - \pi_{PE}^* = \frac{1}{18}\theta\left[\tau(26 - 8\alpha g) + 9\theta - 8\mu(1-\alpha g)\right] > 0, \tag{15}$$

for $\tau \in (\hat{\tau}, \overline{\tau})$, where

$$\hat{\tau} \equiv \frac{8\mu(1-\alpha g) - 9\theta}{26 - 8\alpha g}.$$

Assumption 2 ensures that the range $(\hat{\tau}, \overline{\tau})$ exists. Similarly, inequality $\pi^*_{PP} - \pi^*_{EP} > 0$ may be written as

$$\pi^*_{PP} - \pi^*_{EP} = \frac{1}{18}\theta(8\mu - 8\alpha g(\mu - \theta(2-\alpha g)) - t(26 - 8\alpha g) - 17\theta) > 0, \tag{16}$$

for $\tau < \tilde{\tau}$, where

$$\tilde{\tau} \equiv \frac{\theta\left[8\alpha g(2-\alpha g) - 17\right] + 8\mu(1-\alpha g)}{26 - 8\alpha g},$$

and

$$\hat{\tau} - \tilde{\tau} = \frac{4\theta(1-\alpha g)^2}{13 - 4\alpha g} > 0. \tag{17}$$

Inequality (17) implies that, in the region $t \in (\hat{\tau}, \overline{\tau})$, an *ECSR* industry configuration is a stable steady state, since $\pi^*_{PE} - \pi^*_{EE} > 0$ and $\pi^*_{PP} - \pi^*_{EP} < 0$, so that $\mathbb{E}(\pi^*_E(f)) - \mathbb{E}(\pi^*_P(f)) > 0$ for every f, thus $f^* = 1$. Conversely, a *PS* industry configuration is a stable steady state f^* in $\tau \in (0, \tilde{\tau})$. Indeed in this region, $\pi^*_{PP} - \pi^*_{EP} > 0$ and $\pi^*_{PE} - \pi^*_{EE} > 0$, according to which $\mathbb{E}(\pi^*_P(f)) - \mathbb{E}(\pi^*_E(f)) > 0$ for every f, so that $f^* = 0$.

We are left with the task of evaluating the mixed equilibrium, which emerges whenever the expected profits of choosing the PS or ECSR type are identical. In particular, this occurs in the region $\tau \in (\tilde{\tau}, \hat{\tau})$, because, according to (17), here $\pi^*_{PE} - \pi^*_{EE} > 0$ and $\pi^*_{PP} - \pi^*_{EP} < 0$, namely, there exists $f \in (0,1)$ such that $\mathbb{E}(\pi^*_P) - \mathbb{E}(\pi^*_E) = 0$ and $f^* \in (0,1)$. Note that $\mathbb{E}\pi^*_P(f) = \mathbb{E}\pi^*_E(f)$ requires

$$f^*_{mix} \equiv \frac{\theta\left(8\alpha^2 g^2 - 16\alpha g + 17\right) + 8\mu(\alpha g - 1) + \tau(26 - 8\alpha g)}{8\theta(\alpha g - 1)^2} \in (0,1) \tag{18}$$

for $\tau \in (\tilde{\tau}, \hat{\tau})$. Finally, given that inequality (17) always holds, no unstable mixed equilibria exist. The discussion can be summarised in the following proposition, which outlines the possible steady state industry configurations.

Proposition 2 *Let Assumption 1 and Assumption 2 hold. The industry configuration is*

1. *ECSR ($f^* = 1$) for $\tau \in (\hat{\tau}, \overline{\tau})$;*

3. Mixed ($f^* = f^*_{mix}$) for $\tau \in (\tilde{\tau}, \hat{\tau})$;

3. PS ($f^* = 0$) for $\tau \in (0, \tilde{\tau})$.

The most interesting aspect of Proposition 2 is that an increase in the tax on emissions also pushes the diffusion of ECSR firms. This effect is confirmed by differentiating the equilibrium share of ECSR firms in the *Mixed industry configuration*, yielding

$$\frac{\partial f^*_{mix}}{\partial \tau} = \frac{13 - 4\alpha g}{4\theta(1 - \alpha g)^2} > 0. \tag{19}$$

Thus a higher tax rate strategically favours ECSR firms. The intuition lies on the fact that the increase in the tax entails further abatement which, even though it is applied to both firms, only ECSR firms benefit from in terms of higher demand for green products.

The next corollary illustrates other effects of environmental concern, both of consumers and firms in the steady state in Proposition 2.

Corollary 2 *An increase in the share of green consumers, in their sensitivity to environmental issues or the commitment of ECSR firms to abating their emissions increases the population of ECSR firms.*

Proof. In Appendix.

Intuitively, an increase in the demand of green products, prompted by the share of green consumers or their sensitivity, increases the profitability of choosing a ECSR type. In addition, the demand for green products is also driven by the commitment of the ECSR firm in emission reduction abatement. Together with Proposition 2, the results of Corollary 2 clarify the role played by green consumers in the diffusion of ECSR firms and the strategic role of the tax on emissions in increasing the competitive advantage of ECSR firms by indirectly pushing the demand for green products.

We finally check the impact of changes in market size on the steady state equilibrium.

Corollary 3 *An increase in market size decreases the share of ECSR firms.*

Proof. In Appendix.

Corollary 3 shows that, as market size increases, the demand advantage gained by ECSR firms becomes relatively smaller, all else being equal, including the cost of commitment to reducing emissions.

5 Welfare analysis

By relying on the industry configuration developed in the evolutionary setting, we examine the impact of changes in the share of environmentally conscious consumers in the population and their environmental sensitivity, the commitment of ECSR firms to emission reduction, and the level of emission tax on the steady state. We are particularly interested in examining the transition from a configuration where firms completely ignore their impact on the environment (an *All PS industry configuration*), reflecting the typical situation of a few decades ago, to a configuration in which all firms internalise their environmental impact on production (an *All ECSR industry configuration*), which has not been applied yet at the time of writing this paper. This transition is clearly represented by the *Mixed industry configuration*, illustrated by an increase in the share of ECSR firms. Through this analysis, we clarify the interconnection between consumers' environmental awareness, the voluntary adoption of emission reduction technologies, and the implementation of an emission tax.

We define social welfare as the sum of total industry profits, consumer surplus of subpopulations g (CS_g) and b (CS_b), respectively, and tax revenue T minus environmental damage, ED:

$$W = TIP + CS_g + CS_b + T - ED. \tag{20}$$

In (20), "Total industry profits" TIP amounts to

$$TIP = 2f^*\pi_P^*(f^*) + 2(1-f^*)\pi_E^*(f^*),$$

tax revenue corresponds to

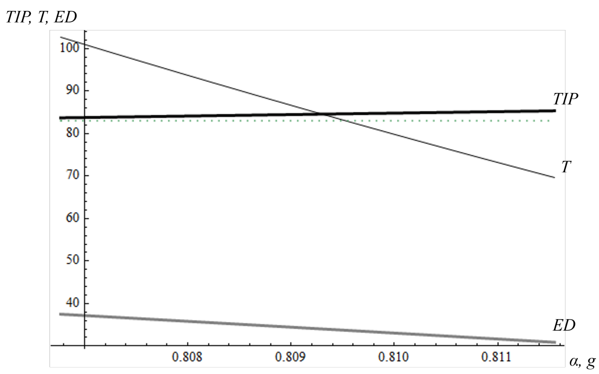
$$T = \tau\left[2f^*(q_P^*(f^*) - z_P^*) + 2(1-f^*)(q_E^*(f^*) - z_E^*)\right], \tag{21}$$

while environmental damage ED is assumed to be a quadratic function of the industry's polluting emissions,

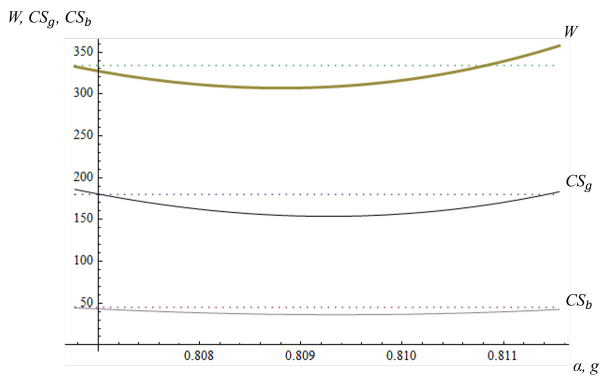
$$ED = [2f^*(q_P^*(f^*) - z_P^*) + 2(1 - f^*)(q_E^*(f^*) - z_E^*)]^2 . \tag{22}$$

In what follows, we describe the effects of variations in α, g, θ, and τ on social welfare and its components through numerical simulation. The parameter values are chosen such that Assumption 1 and Assumption 2 hold. Specifically, we set $\mu = 30$ and $g = 0.8$, $\alpha = 0.8$, $\theta = 0.8$, and $\tau = 3.7$. Results are qualitatively similar using different parameter values, provided the aforementioned restrictions hold. In Panel (a) of each figure, we illustrate how TIP, ED, and T respond to changes in the parameter values. Moreover, a horizontal dotted line is included to indicate the positive gradient in TIP. In Panel (b) of each figure, we examine the effects on the consumer surplus of both consumer types and social welfare resulting from changes in the parameter values. Once more, three horizontal dotted lines are added to highlight the differences in absolute values between low and high parameter values.

Finally, it is important to note that, according to Equation (19) and Corollary 2, an increase in g, α, θ, or τ results in an increase in the share of ECSR firms. The parameter ranges considered in the analysis below span from an industry configuration with only PS firms to one with only ECSR firms, encompassing all possible mixed combinations in between.



(a) TIP, environmental damage, tax revenue.



(b) Consumer suprlus and socia welfare

Fig. 1. Changes in the proportion of green consumers or in their environmental concern

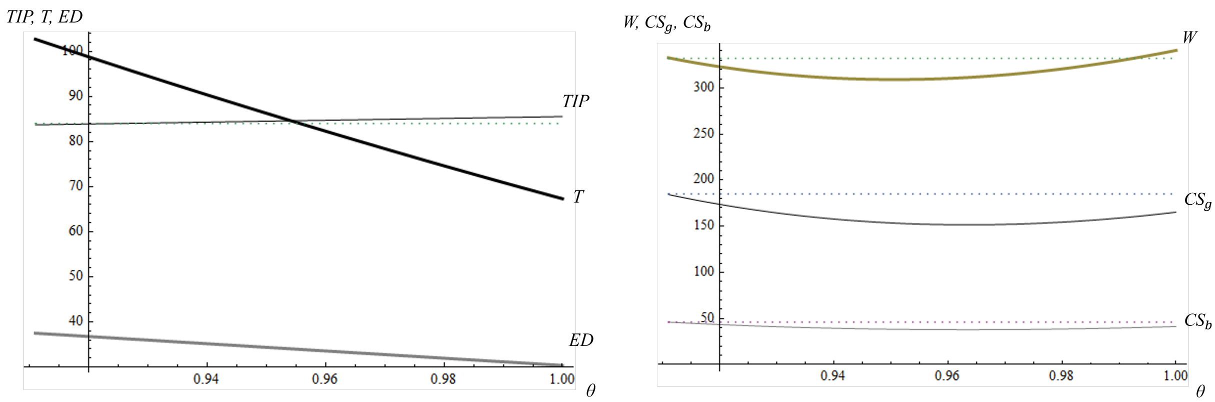
Begin with consumers' environmental concern. In the analysis, this can be represented by the share of green consumers, denoted as g, and by their level of environmental awareness, represented by α. Changes in both g and α have the same effect, this is because they are multiplicative of each other in any equilibrium function. This implies that a variation in each of these parameters yields the same effect on each social welfare component. Intuitively, according to Fig. 1(a), environmental damage and tax revenue decrease with an increase in consumers' environmental concern. This is natural to expect, considering that, as per Corollary 2, an increase in g or α leads to a higher proportion of ECSR firms, which abate pollution more effectively than PS firms. The consequence of a higher proportion of ECSR firms is reduced environmental damage and tax revenues, since these depend on the level of polluting emissions. Total industry profits appear to increase slightly: in a scenario where the share of ECSR firms is higher than that of PS firms, the increase in demand for green goods more than compensates for the increase in the cost of investment in emission reduction.

The most interesting result is what shown in Fig. 1(b): as the share of green consumers (or their sensitivity) increases, social welfare first decreases and then increases. As emphasised earlier, this is accompanied by an increase in the share of ECSR firms. Thus, at a certain point in the mixed industry configuration, social welfare reaches its minimum. As $g(\alpha)$ increases further, the final level of social welfare with only ECSR firms appears to be the social optimum. This result is clearly driven by the dynamics of consumer surplus, which follows the same trajectory. The intuition is simple if we look at the variation of prices and quantities with respect to a change in the share of ECSR firms, namely,

$$\frac{\partial p_{k\omega}^*}{\partial f_{mix}^*} = \frac{\partial x_{k\omega}^*}{\partial f_{mix}^*} = \frac{2\theta(1-\alpha g)}{3} > 0, \text{ for every } k \in \{P, E\}, \omega \in \{g, b\}.$$

All equilibrium prices and quantities increase with an increase in ECSR firms, indicating contrasting competitive forces. A lower level of competition between firms of different types occurs when the proportion of firms of each type is similar because, in this case, the number of vertically differentiated goods is the highest. However, with many PS or ECSR firms, competition is stronger on average, and consumers reap the benefits from it.

The economic implications are striking. In the short run, there are no social incentives to increase consumers' environmental concern. In terms of policy, for instance, this could be achieved by using tax revenues to promote environmental awareness through advertising, sensitivity campaigns, and so on. If the initial conditions of the industry involve only PS firms or a large share of them, the positive effects of such a policy would only be observed once the industry has completely changed its configuration, which takes time. In contrast, the short-run effects would be negative, impacting the well-being of consumers. We do not model the political economy behind the adoption of such policies, but one can intuitively see the trade-off in implementing policies promoting environmental awareness once the government has a short-run mandate.

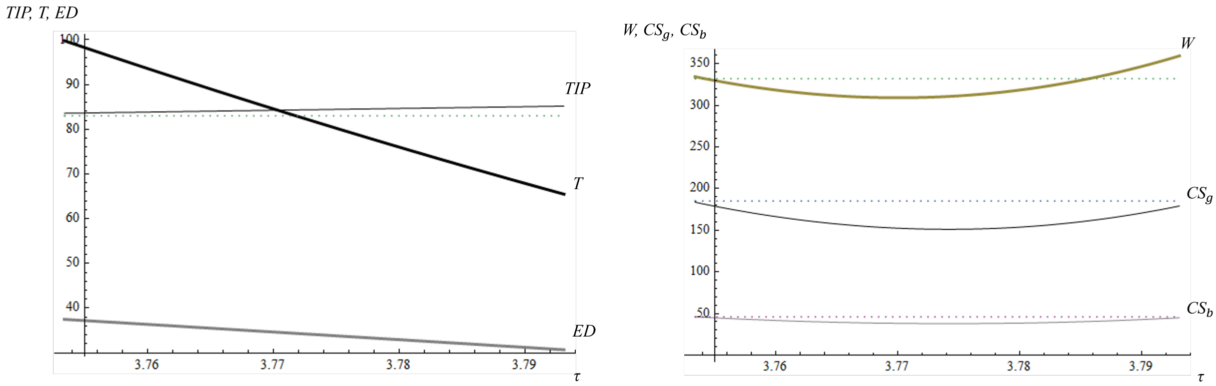


(a) TIP, environmental damage, tax revenue. **(b)** Consumer suprlus and socia welfare

Fig. 2. Changes in ECSR's emission reduction commitment.

Fig. 2 and Fig. 3 illustrate the changes in social welfare and its components due to variations in ECSR firms' environmental concern and emissions tax. Equations (19) and Corollary 2 have already shown that these parameters behave similarly to consumers' environmental concern. Accordingly, the depicted results are qualitatively similar: an increase in θ or τ has the same effect as g and α on social welfare and each of its components.

However, there is an important difference in the variation of ECSR's environmental commitment compared to τ, g, and α: indeed, θ is determined by firms, and Fig. 2(a) has shown that there is a private incentive to increase environmental concern because of its positive (although slight) effect on profits. Thus, an increase in the private commitment to environmental awareness by firms seems more viable compared to public intervention in achieving both the social optimum and the least impact of the industry on the environment.



(a) TIP, environmental damage, tax revenue.

(b) Consumer suprlus and social welfare

Fig. 3. Changes in the tax on emissions.

6 Concluding remarks

We have analysed the role played by consumers' environmental concern in the transition towards sustainable production. In an industry where a segment of consumers are environmentally conscious, we determine the steady-state equilibrium where firms choose to adopt or not ECSR activities. Our results show that there are no social incentives to promote a transition towards sustainable production. This is because, initially, the transition brings about a fall in social welfare, driven by a fall in consumer surplus.

In contrast, firms may have an incentive to engage in ECSR activities autonomously and to drive the transition towards sustainable production, as an increase in the share of ECSR firms leads to an increase in profits. Thus, our results suggest that private rather than social incentives may help to push the adoption of sustainable production strategies. A policy implication is that public incentives for firms to change their production strategy appear to be more effective and politically feasible in the long run than increasing the tax rate on emissions.

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Appendix

Proof of Corollary 1

Equilibrium quantities of P firms are positive for

$$\tau < \tau_{x_P} \equiv \mu + \theta m(1 - \alpha g),$$

while equilibrium quantities of P firms are positive for

$$\tau < \tau_{x'_E} \equiv \mu - \theta(N + 1 - m)(1 - \alpha g),$$

where

$$\tau_{x_P} - \tau_{x'_E} = \theta(1 + N)(1 - \alpha g) > 0,$$

so that $\tau_{x'_E}$ is binding. Since τ'_{x_E} is increasing in m, then $\tau < \tau_{x_E}$, where

$$\tau < \tau_{x_E} \equiv \mu - \theta\,(N + 1)\,(1 - \alpha g),$$

ensures the positivity of equilibrium quantities for every $m \in \{0, ..., N\}$.

Equilibrium emissions of P firms are positive for

$$\tau < \tau_{e_P} \equiv \frac{\mu + \theta m(1 - \alpha g)}{N + 2},$$

while equilibrium emissions of E firms are positive for

$$\tau < \tau'_{e_E} \equiv \frac{\mu + \theta[m(1 - \alpha g) - (N + 1)(2 - \alpha g)]}{N + 2},$$

where

$$\tau_{e_P} - \tau'_{e_E} = \frac{\theta(N + 1)(2 - \alpha g)}{N + 2},$$

so that τ'_{e_E} is binding. Since τ'_{e_E} is increasing in m, then $\tau < \tau_{e_E}$, where

$$\tau < \tau_{e_E} \equiv \frac{\mu - \theta(N+1)(2-\alpha g)}{N+2},$$

ensures the positivity of equilibrium quantities for every $m \in \{0, ..., N\}$.

Therefore $\tau < \overline{\tau} \equiv \min\{\tau_{x_E}, \tau_{e_E}\}$ ensures positivity of equilibrium quantities

Proof of Lemma 1

In order an industry composed of only ECSR firm ay emerge, one necessary condition is $\pi^*_{EE} > \pi^*_{PE}$, that is

$$\pi^*_{EE} - \pi^*_{PE} = \frac{1}{18}\theta(8\mu(\alpha g - 1) + \tau(26 - 8\alpha g) + 9\theta) > 0,$$

if and only if $\tau > \hat{\tau}$, where

$$\hat{\tau} \equiv \frac{8\mu(1-\alpha g) - 9\theta}{26 - 8\alpha g}.$$

By Corollary 1, then τ may be higher than $\hat{\tau}$ only if $\hat{\tau} < \overline{\tau}$. Since $\overline{\tau} = \min\{\tau_{x_E}, \tau_{e_E}\}$ takes the minimum of two values, this requires two sufficient conditions. The first condition is $\hat{\tau} < \tau_{x_E}$, that is,

$$\frac{18\mu - 3\theta\left[23 - 2\alpha g(17 - 4\alpha g)\right]}{26 - 8\alpha g} > 0,$$

which occurs if

$$\mu > \frac{\theta}{6}\left(23 + 8\alpha^2 g^2 - 34\alpha g\right).$$

The second condition is $\hat{\tau} < \tau_{e_E}$, which requires

$$\frac{3\left[\mu(1 - 4\alpha g) + \theta(4 - \alpha g)(5 - 4\alpha g)\right]}{52 - 16\alpha g} > 0,$$

and occurs if

$$\mu > \frac{\theta(4 - \alpha g)(5 - 4\alpha g)}{4\alpha g - 1}.$$

Proof of Corollary 2

Differentiating $\hat{\tau}$, $\tilde{\tau}$ and f^*_{mix} with respect to α and g yields, respectively,

$$\frac{\partial\hat{\tau}}{\partial\alpha} = \frac{\partial\hat{\tau}}{\partial g} = -\frac{18g(\theta + 2\mu)}{(13 - 4\alpha g)^2} < 0,$$

$$\frac{\partial\tilde{\tau}}{\partial\alpha} = \frac{\partial\tilde{\tau}}{\partial g} = \frac{2g\left(\theta\left(8\alpha^2 g^2 - 52\alpha g + 35\right) - 18\mu\right)}{(13 - 4\alpha g)^2} < 0, \ \textit{for}\ \mu > \hat{\mu},$$

$$\frac{\partial f^*_{mix}}{\partial\alpha} = \frac{\partial f^*_{mix}}{\partial g} = \frac{g(4\mu(\alpha g - 1) + \tau(22 - 4\alpha g) + 9\theta)}{4\theta(1 - \alpha g)^3} > 0, \ \textit{for}\ \mu > \hat{\mu}.$$

Differentiating $\hat{\tau}$, $\tilde{\tau}$ and f^*_{mix} with respect to θ yields, respectively,

$$\frac{\partial\hat{\tau}}{\partial\theta} = \frac{9}{8\alpha g - 26} < 0,$$

$$\frac{\partial\tilde{\tau}}{\partial\theta} = \frac{8\alpha g(\alpha g - 2) + 17}{8\alpha g - 26} < 0,$$

$$\frac{\partial f^*_{mix}}{\partial\theta} = \frac{4\mu(1 - \alpha g) - t(13 - 4\alpha g)}{4\theta^2(1 - \alpha g)^2} > 0 \ \textit{for}\ \mu > \hat{\mu}.$$

Proof of Corollary 3

Differentiating $\hat{\tau}$, $\tilde{\tau}$ and f^*_{mix} with respect to μ yields, respectively,

$$\frac{\partial\hat{\tau}}{\partial\mu} = \frac{\partial\tilde{\tau}}{\partial\mu} = \frac{4 - 4\alpha g}{13 - 4\alpha g} > 0,$$

$$\frac{\partial f^*_{mix}}{\partial\mu} = \frac{1}{\theta - \alpha g\theta} > 0.$$