Environmental and Resource Economics
https://doi.org/10.1007/s10640-025-01028-3

Green Consumers and the Transition to Sustainable Production

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Accepted: 28 July 2025

Abstract
We investigate the interaction between consumers' environmental concern, environmental corporate social responsibility (ECSR), and environmental regulation 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 (Games Econ Behav 40(2):232–269, 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.

Keywords Mixed duopoly markets · Emission reduction investment · Evolutionary dynamics

JEL Code C73 · H23 · L13 · L21 · M14

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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 firms. Indeed, the relationship between the growth of green consumerism and firms' investment in abatement technologies or eco-innovation is well documented (Nekmahmud and Fekete-Farkas 2020). To make an example by referring to a whole economy, Doran and Ryan (2016) examine a sample of 2,148 Irish firms and show that, as consumer awareness of environmental issues increases, firms are increasingly motivated to invest in green innovation. With a focus on a specific industry, Wüstenhagen and Bilharz (2006) analyse the development of renewable energy in the German energy market from 1973 to 2003. They find that increased consumer demand for sustainable products played a central role in promoting renewable energy production in the German energy market.

While much of the literature on environmental regulation already acknowledges the presence of environmentally conscious consumers),[2] the effects of a change in their proportion in the population and its implications for firms and policy choices have not yet been thoroughly investigated. What is missing is an understanding of how an increase in the number of environmentally concerned consumers and their sensitivity to environmental issues affects the choice of firms to adopt environmentally sustainable production. Understanding how consumer environmental awareness affects firms' production strategy with respect to their environmental impact is the very scope of this paper.

We study how consumers' environmental concerns interact with environmental regulation in the transition to sustainable production. Throughout the paper, we define *sustainable production* as a production strategy that takes into account and internalises its polluting emissions. In our model, sustainable production is adopted by firms that engage in environ-

[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).

mental corporate social responsibility. The *transition* takes place in a scenario in which all firms in the industry adopt an environmental corporate social responsibility statute.

In general, *Environmental Corporate Social Responsibility* (ECSR) refers to a firm's commitment to minimise its negative impact on the natural environment through sustainable practices, resource conservation and pollution reduction. The concept of integrating environmental concerns into corporate social responsibility (CSR) has evolved over time as firms and academics have recognised the importance of environmental concern alongside social and economic responsibilities.

We model consumers' environmental concern as the share of environmentally aware consumers in the population and their {*sensitivity* to environmental issues, i.e., their willingness to pay for goods whose production process has taken into account their environmental impact. A firm could choose to ignore its environmental impact and pursue standard profit-seeking. 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 (profit-seeking or ECSR) in an evolutionary Cournot duopoly *à la* Droste et al. (2002): in each time period, the board of directors of each duopolist selects a manager among a large population, committed to apply either the profit-seeking or ECSR production strategy. The choice is based on the expected profits of the previous period. Once appointed the manager, the firms compete in quantity and choose their level of emission reduction investment. In this way, the probability to choose a profit-seeking or ECSR type evolves over time according to the profits realised in the quantity game.

A real-world example that fits the industry configuration and the phenomena at hand is the cola beverages industry, which is dominated by Coca-Cola and PepsiCo. These firms have increasingly integrated sustainability into their corporate strategies in response to rising consumer and regulatory demand for sustainable products. This has influenced their decision to invest in environmental corporate social responsibility activities, such as reducing emissions, improving water use and innovating recyclable and reusable packaging (see for example PepsiCo, (2023), Pyzyk (2024), Credits (2025) and Company (2025). Therefore, their sustainability efforts are strategic responses to growing demand for sustainability.

Our results show that the transition to a production style that voluntarily reduces its emissions 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 industry is composed of a similar proportion of firms of different types, then the firms obtain their highest market power, which reduces the benefits to consumers.

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. {In turn, our results support the "weak" version of the Porter Hypothesis, according to which the emission reduction innovation driven by environmental regulation can increase firms' profits (Jaffe and Palmer 1997).

The remainder of the paper is organised as follows. Section 2 briefly surveys the relevant literature. Section 3 develops the framework, while Sect. 4 outlines the static duopoly setting, preliminary to the evolutionary analysis, in which firms take their competitors' type and their own as given. Section 5 analyses the long-run industry configuration in an evolutionary duopoly setting where firms endogenously set their own type. Welfare analysis is developed in Sect. 6, while Sect.7 extends the baseline analysis by considering different abatement technology or different assumptions on the dynamical system. Section 8 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.

In economic theory, the concept of ECSR has developed in the last two decades from the more general definition of CSR with a focus on environmental issues.[3] The body of work on ECSR has its roots in the extensive research on strategic CSR (Baron 2001). This research is predominantly concerned with social issues faced by firms rather than environmental issues (early contributions are Goering 2007; Kopel and Brand 2012). The strategic CSR literature itself has its origins in the foundational studies of mixed oligopolies, as reviewed by De Fraja and Delbono (1990). For the sake of focus and brevity, we will not discuss these areas of literature here.

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; Xu and Lee 2022, Xu et al. 2022; Iannucci and Tampieri 2023). In this strand of the literature, ECSR practices can also be interpreted as managerial delegation, where the manager's contract is based on the amount of environmental tax savings achieved by reducing emissions. 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. 2023). A common finding in this research is that firms can engage in ECSR activities to achieve greater profitability than their competitors. This is due to the fact that integrating social concern into the production strategy increases productivity, which more than offsets the additional costs of environmental abatement. Our paper fits into this strand of literature because the endogenous determination of firm types is interpreted as managerial delegation, i.e. the choice of managers made by the firm's board of directors.

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

[3] Lyon and Maxwell (2008) reviews the theoretical literature on ECSR, the reasons for adopting environmental corporate social responsibility and its welfare effects. In particular, both strategic and altruistic reasons are considered. Here we focus on the former.

been adopted, for instance, by Manasakis et al. (2013, 2014), Liu et al. (2015), Xu and Lee (2023) and Fang and Zhao (2023). With this methodology, the results are qualitatively similar to those obtained with the previous approach: given appropriate parameter values, ECSR firms produce more and make higher profits than their counterparts. Here, the practice of reducing emissions further stimulates demand, so that the cost of environmental responsibility is offset by green consumers choosing ECSR products over standard goods.

This paper is primarily related to these latter contributions by incorporating environmentally conscious consumers into the analysis. We extend the previous contributions by analysing how the size of the proportion of green consumers, as well as their level of sensitivity to environmental issues, influences firms' decision-making regarding profits 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.[4]

The paper is also linked to the literature on environmental regulation in oligopolies. Most parts of the literature have focused on static models in which the regulatory intervention takes the shape of a tax on emissions (see Poyago-Theotoky 2007; Ouchida and Goto 2016; Lambertini et al. 2017; Mc Donald and Poyago-Theotoky 2017; Buccella et al. 2021, Xu et al. 2022; 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 (rather than a tax on emissions) in evolutionary settings and perfect competition (rather than an oligopoly) when consumers are not environmentally concerned, see Antoci et al. (2019), Antoci et al. 2020 and Antoci et al. (2021). In general, they find the conditions under which an emissions trading system promotes the diffusion of green technologies, as well as the conditions under which it provides an incentive to relocate to unregulated countries. The present analysis is related to many of these papers but, unlike them, it allows us to see how the introduction of an emissions tax and its level 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. 2023). The analysis of an evolutionary setting is relevant since it allows us to study the long-run market configuration in a mixed market. In general, these contributions find the conditions under which a market is mixed or homogeneous in terms of production strategy.

Regarding the papers of this literature, our work is mainly related to Iannucci and Tampieri (2023) and (Buccella et al. 2023). 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

[4] Ambec and De Donder (2022) study perfect competition and compare different policy types (emission standard with Pigouvian tax) with green and brown consumers. They find that emissions taxes are less economically efficient than emissions standards. This inefficiency stems from the fact that taxes lead to greater variation in the environmental quality of products. Despite this, consumers tend to view taxes more favourably than strict regulatory standards, but only when the 'warm glow' derived from their environmental choice is relatively modest, and vice versa.

pressures by increasing the number of firms in the market, treating the emission tax as exogenous. In contrast, (Buccella et al. 2023) 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. 2023) 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). Compared to these papers, the main innovation lies in integrating a portion of environmentally conscious consumers into this framework: the impact of changes in the proportion of these consumers in the steady state and their degree of environmental concern is one of the main points of this present paper.

Finally, the results of this paper confirm the Porter hypothesis in its weak version. In the literature on environmental regulation, this result has been supported in static frameworks by André et al. (2009), Lambertini and Tampieri (2012) and Lambertini et al. (2020), Ranocchia and Lambertini (2021) and in an evolutionary framework by Iannucci and Tampieri (2023). Our welfare analysis shows that an increase in the tax rate stimulates investment in abatement, which in turn drives firms to become ECSRs.

3 The Model

We analyse a duopoly composed of 2 firms, 1 and 2, that produce a unique good and compete *à la* Cournot. Each firm can be of two types: profit-seeking (P) or environmentally socially concerned (E).

In the preliminary, static analysis (Sect. 4), a firm's type is assumed to be given and firms compete in terms of quantities and investment in emission reductions to determine equilibrium profits. By contrast, in the (main) evolutionary analysis (Sect. 5 onwards), a firm's type evolves endogenously, guided by the equilibrium profits obtained in the static setting.

3.1 Demand Side

The industry serves a population of consumers of measure normalised to one. This population is composed of two subpopulations, which differ in their environmental concern. In particular, there are $g \in [0, 1]$ "green" consumers and $b = 1 - g$ "brown" consumers, indexed by $\omega \in \{g, b\}$. This proportion is taken as given throughout the analysis. The utility of the representative consumer ω, depends on the types of firms in the industry, and is given by:

$$\begin{aligned} U_\omega =& a\left(x_i + x_j\right) + \mathbb{1}_{\{\omega=g, i=E\}}\alpha\theta x_i + \mathbb{1}_{\{\omega=g, j=E\}}\alpha\theta x_j - \\ & \frac{1}{2}\left(x_i + x_j - \gamma x_i x_j\right)^2 + c_0, \end{aligned} \tag{1}$$

where $i \in \{1, 2\}$ is a generic firm and $j \neq i$ is its competitor. Moreover, consumer ω's budget constraint is given by

$$I = p_i x_i + p_j x_j + c_0. \tag{2}$$

Utility in Eq. (1) is the standard linear-quadratic utility function by Dixit (1979) and Singh and Vives (1984), extended to vertical differentiation by Häckner (2000). In equations Eq. (1) and Eq. (2), x_i andx_j represent the goods produced by firm i and j, and each can be of type P or E, respectively. 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 produced by different types of firms. 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 {between goods produced by firms of different types. In particular, while the willingness to pay $a > 0$ is the same between green and brown consumers, the formers are happy to pay an extra $\alpha\theta$ for each unit purchased from an E firm. This assumption is supported by empirical evidence. For example, PwC (2024)'s report shows that some consumers are willing to pay an average of 9.7% more for sustainable products, despite concerns about the cost of living and inflation.

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 E's sensitivity to abate its own polluting emissions (see the section later for details). We may thus interpret α as the green consumers' degree of environmental concern.[5] The fact that only consumers of type g are willing to pay an extra $\alpha\theta$ is represented by the indicator functions $\mathbb{1}_{\{\omega=g, i=E\}}$ and $\mathbb{1}_{\{\omega=g, j=E\}}$, which take value 1 if $\omega = g$ and $i = E$ or $j = E$, and take value of 0 otherwise.

This context may be interpreted as follows. All goods produced in the industry are homogeneous for their intrinsic value to consumers, but differ in their production process by firm types. In particular, E goods are produced by internalising the environmental impacts of their production, while P goods are produced without regard to this. Given the differences only in the production process, brown consumers value products from P and E firms in the same way, so for them all goods are homogeneous ($\mathbb{1}_{\{\omega=b\}} = 0$). Instead, green consumers place a higher value on the products of E firms ($\mathbb{1}_{\{\omega=g\}} = 1$), so they are willing to pay a higher price for them. This model mirrors the ongoing example of cola beverages,[6] where cola is largely a homogeneous good, but environmentally conscious individuals are willing to pay more for a soft drink produced in a sustainable way.[7] For every consumer $\omega \in \{g, b\}$, utility maximisation of Eq. (1) with respect to each good x_i subject to budget constraint Eq. (2) yields the following inverse demand for the good produced by firm i and consumed by consumer ω:

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

[6] Another example of an industry that may be well represented by products with these characteristics is the bottled water industry. Bottled water is relatively standardised, with little differentiation in the actual product (water), regardless of the producer. Most consumers see it as a homogeneous product that is mainly differentiated by its branding and packaging. However, some firms use more sustainable production methods, such as energy-efficient bottling plants or reduced reliance on fossil fuels. So while the product itself may be similar from one producer to another, their environmental practices can vary significantly, which in turn influences consumer choice.

[7] Lee et al. (2018) show that consumers are more likely to pay extra for truly sustainable products. Accordingly, Coca-Cola's PlantBottle initiative, which uses plant-based materials for packaging, responds to this demand. In addition, Lee et al. (2018) found that consumers are discerning and will not pay more if they perceive the sustainability claims as superficial or insubstantial.

$$p_{i\omega}(x_i, x_j) = a + \mathbb{1}_{\{i=E,\omega=g\}}\alpha\theta - x_i - x_j, \tag{3}$$

where $\mathbb{1}_{\{i=E,\omega=g\}}$ is an indicator function taking values of 1 if the firm is of type E and the consumer is of type g, and zero otherwise. This implies that goods produced by P firms are valued equally by green and brown consumers, and this is the same value that brown consumers place to E products: $\mathbb{1}_{\{k=P,\omega=b\}} = \mathbb{1}_{\{k=P,\omega=g\}} = \mathbb{1}_{\{k=E,\omega=b\}} = 0$.

3.2 Supply Side

We assume that E firms are able to discriminate prices according to the type of consumer: this can be interpreted as differences in income, level of education or political orientation between b and g-type consumers. In contrast, P firms face the same inverse demand, regardless of the consumer's type.

Firms of both types are subject to emission taxation, creating an incentive for each of 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, reduces the release of pollutants into the atmosphere but does not eliminate environmental damage. Examples include catalytic converters installed in vehicle exhaust systems, and filters that prevent releasing emissions (Lahiri and Symeonidis 2007). In this case, the technology is thus set at the end of the production process, thus its cost does not depend on a firm's production level.[8] Going back to our working example, Coca-Cola improved packaging recyclability and waste management, which are often considered downstream or end-of-pipe environmental strategies. Indeed, these efforts address plastic pollution and waste through recycling and collection rather than eliminating plastic waste at the source (Trash 2020).

In addition, following the literature on (environmental) innovation (see, for example, d'Aspremont and Jacquemin 1988; Ulph 1996; Poyago-Theotoky 2007), we assume that investment in abatement technology is quadratic, reflecting that it is characterised by decreasing returns.

For firm i serving the demand of ω-consumers, profits are given by:

$$\pi_{i\omega} = [p_{i\omega}(x_i, x_j) - c]\, x_i - \frac{z_i^2}{2} - e_i\tau, \tag{4}$$

with $e_i = x_i - z_i$. In, Eq. (4), $c>0$ represents the unit production cost, z_i denotes investment in emissions abatement, and τ is the Pigouvian tax unit on emissions. For each firm i competing with firm j, overall profits are:

$$\Pi_{ij} = g\pi_{ig} + (1-g)\pi_{ib}. \tag{5}$$

Note that the distinction between π_{ig} and π_{ib} is, in fact, relevant only for E firms, as the demand for P products reflects the same willingness to pay from both g and b consumers.

In its maximisation process, a firm i of type E maximises its profits by also internalising its share of emissions. The objective function of a firm i of type E competing with firm j is thus:

[8] On Sect. 7.1, we extend the analysis by assuming, in alternative, a cleaner production technology.

$$O_{ij} = \Pi_{ij} - \theta e_i, \tag{6}$$

where $\theta \in [0, 1]$ denotes the proportion of emissions that are voluntarily internalised by an E firm.

4 Preliminaries: Static Analysis

In this section, each firm of the industry takes its own type and that of the competitor as given. The equilibrium is static: firms simultaneously set their quantities and their investment in emissions reduction technology based on their objective function. Profits are achieved strategically through Nash behaviour. The static analysis carried out in this section is functional to develop our framework in a dynamic, evolutionary setting in the next section, where each firm's type is endogenously determined.

A firm i of type P maximises overall profits Π_{ij} with respect to quantities and investment in emission reduction technology:

$$\max_{x_i, z_i} \Pi_{ij} = \max_{x_i, z_i} \left[g p_{ig}(x_i, x_j) + (1-g) p_{ib}(x_i, x_j) - c \right] x_P - \frac{z_i^2}{2} - e_i \tau, \tag{7}$$

In contrast, if firm i is of type E maximises its objective function O_{ij}, i.e.,

$$\max_{x_i, z_i} O_{ij} = \max_{x_i, z_i} \left[g p_{ig}(x_i, x_j) + (1-g) p_{ib}(x_i, x_j) - c \right] x_i - \frac{z_i^2}{2} - e_i(\tau + \theta). \tag{8}$$

To ease the exposition, in what follows we set $\mu = a - c$, where μ represents market size.[9] The first order conditions of Eq. (7) and Eq. (8) with respect to x_i and z_i are, respectively,

$$\frac{\partial \Pi_{ij}}{\partial x_i} = \mu - \tau - 2x_i - x_j = 0, \tag{9}$$

$$\frac{\partial \Pi_{ij}}{\partial z_i} = \tau - z_i = 0, \tag{10}$$

$$\frac{\partial O_{ij}}{\partial x_i} = \mu - \tau - \theta\,(1 - g\alpha) - 2x_i - 2x_j = 0, \tag{11}$$

[9] The interpretation of $a-c$ as market size is standard in the analysis with linear demand and costant marginal costs, for any industry configuration (perfect competition, oligopoly or monopoly). Indeed, for $a<c$, production is zero, while for $a>c$, production is positive and the equilibrium quantity linearly depends on $a-c$ (Shy 1996, pp. 64–66).

and

$$\frac{\partial O_{ij}}{\partial z_i} = \tau + \theta - z_i = 0. \tag{12}$$

From Eqs. (9) and (11), we can appreciate the strategic interaction between firms, from which we may easily obtain the following reaction functions:

$$x_i(x_j) = \frac{1}{2}\left(\mu - \tau - x_j\right), \tag{13}$$

$$x_i(x_j) = \frac{1}{2}\left[\mu - \tau - \theta\left(1 - g\alpha\right) - x_j\right], \tag{14}$$

respectively, while, from Eqs. (10) and (12), the decision over emission reduction technology solely interacts with the level of tax rate.

The elements of market equilibrium are summarised as follows.

Proposition 1 *Equilibrium quantities and investments in emission reduction are,*

- for $i = j = P$,

$$x^*_{PP} = \frac{\mu - \tau}{3}, \qquad z^*_{PP} = \tau;$$

- for $i = j = E$,

$$x^*_{EE} = \frac{\mu - \tau - \theta\left(1 - \alpha g\right)}{3}, \qquad z^*_{EE} = \theta + \tau;$$

- for i=P and j=E,

$$x^*_{PE} = \frac{\mu - \tau + \theta\left(1 - \alpha g\right)}{3}, \qquad z^*_{PE} = \tau,$$

$$x^*_{EP} = \frac{\mu - \tau - 2\theta(1 - \alpha g)}{3}, \qquad z^*_{EP} = \theta + \tau.$$

Proposition 1 shows the equilibrium quantities produced in each possible industry configuration in the duopoly. Using the results of Proposition 1, we are able to show the equilibrium profits for each industry configuration, that is

$$\begin{aligned} \Pi^*_{PP} &= \frac{1}{18}\left(2\mu^2 + 11\tau^2 - 4\mu\tau\right), \\ \Pi^*_{EE} &= \frac{1}{18}\left[\theta^2(11 - 2\alpha g(2 - \alpha g)) + \tau(\theta(22 - 4\alpha g) - 4\mu) + 2\mu^2 + 11\tau^2 - 4\theta\mu(1 - \alpha g)\right], \end{aligned} \tag{15}$$

for homogeneous industries with both firms of type P or E, respectively, and

$$\Pi^*_{PE} = \frac{1}{18}\left[2(\theta(1-\alpha g)+\mu)^2 + 11\tau^2 - 4\mu\tau - 4\theta\tau(1-\alpha g)\right],$$
$$\Pi^*_{EP} = \frac{1}{18}\left[\theta^2\left(8\alpha^2 g^2 - 16\alpha g + 17\right) + 2\theta\tau(13-4\alpha g) + 2\mu^2 + 11\tau^2 - 4\mu\tau - 8\theta\mu(1-\alpha g)\right], \tag{16}$$

for a mixed industry with one firm of type P and one of type E. A quick look at Proposition 1 shows that both quantities increase with market size (μ) and decrease with the unit tax (τ). Additionally, in the mixed industry, the equilibrium quantities of a P firm increase with the share of emissions that the E competitor is willing to internalise, (θ). Intuitively, by taking into account emission abatement, the E firm puts a lower weight on output than the P rival, who is strategically induced to increase its production level. This result is consistent with what found in the literature of mixed market with ECSR firms (see, for instance, Lambertini and Tampieri 2015; Iannucci and Tampieri 2023; Xu and Lee 2023; Iannucci and Tampieri 2024).

In addition, the increase in quantities of the P firm due to E's internalisation decreases with green consumers' sensitivity to environmental issues (α) (see also Xu and Lee 2023 for a similar result). Unlike the existing literature, our framework allows to determine that the increase in quantities of the P firm due to E's internalisation decreases also with their share in the population (g). This seems natural, considering that both α and g somewhat increase the demand for E firms.

Intuitively, these effects are reversed for E firms: their quantities decrease with emission internalisation, which has the same effect of higher production costs. This effect decreases with the share of green consumers and their sensitivity to environmental concerns.

Finally, note that investment in abatement technology depends strictly on the Pigouvian tax: without it, a P firm has no incentive to invest, because in this case the investment would just be an unmotivated extra cost (Lambertini and Tampieri 2023). For an E firm, on the other hand, abatement investment depends on the tax and on the self-imposed level of abatement, θ.

Next, we evaluate the differences in terms of emissions between firm types. Plugging equilibrium quantities and emission reduction investments by Proposition 1, the equilibrium emission for each firm P and each firm E may be summarised as follows.

Corollary 1 *Equilibrium emissions are,*

- *for* $i = j = P$,

$$e^*_{PP} = \frac{\mu - 4\tau}{3};$$

- *for* $i = j = E$,

$$e^*_{EE} = \frac{\mu - 4\tau - \theta(4-\alpha g)}{3};$$

- *for* i=P and j=E,

$$e^*_{PE} = \frac{\mu - 4\tau + \theta\left(1 - \alpha g\right)}{3}, \qquad e^*_{EP} = \frac{\mu - 4\tau - \theta(5 - 2\alpha g)}{3}.$$

From Corollary 1, one may verify that $e^*_{PP} \geq e^*_{PE} > e^*_{EE} \geq e^*_{EP}$. Intuitively, P firms pollute more than E firms, according to the level of E's emission internalisation θ.

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

Corollary 2 *In every industry configuration, both types of firms exhibit positive equilibrium quantities and emissions for* $\tau < \overline{\tau}$, *where*

$$\overline{\tau} \equiv \min\left\{\mu - 2\theta\left(1 - \alpha g\right), \frac{\mu - \theta\left(5 - 2\alpha g\right)}{4}\right\}.$$

Proof In Appendix.

The restrictions of Corollary 2 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 $\tau < \overline{\tau}$.

5 Evolutionary Duopoly

In this section, we assume that the firms' type choices are endogenously determined. More precisely, we assume that there is an initial stage of the game before market competition, where the Board of Directors of each firm (acting with profit-seeking intentions) selects a manager whose preferences are consistent with either P or E, as suggested, for example, by Schaffer (1989) or Kopel et al. (2014). Going back to our working example: in late 2024 Coca Cola scaled down some carbon emissions targets, switching to a managerial orientation less committed toward sustainability (Credits 2024).

We consider the duopoly played infinitely in continuous time. In each time period t, the Board of Directors of each firm appoints a manager based on the basis of expected profits. There is a large population of managers. Each manager commits to apply, either the P or the E production strategy.),[10] We assume that the Board of Directors has naive expectations about its comperitor's output. In other words, each firm bases its expectations about its competitor's future output on the quantities observed in the current period.

[10] There is substantial evidence that managers with different orientation toward environmental issues are present. See of evidence shows the coexistence of these managerial styles. See, for instance, Sen and Bhattacharya (2001), González-Benito and González-Benito (2008), Baumgartner (2014) and Testa et al. (2018).

Notice that managers commit to play either P or E as pure strategies. Then the natural evolution of the evolutionary model will lead to the survival of more or fewer managers of a certain type, and consequently of that strategy.

5.1 Population of Managers and Expected Profits

At each time period t, a fraction $f \in [0, 1]$ of the population of managers is of the type (i.e., follows the production strategy) E, while a fraction $1 - f$ is of the P type.

In every t, two managers are selected from the population of an E or P type by comparing the expected profits associated with the two objectives. Subsequently, managers determine their output and emission reduction technology to maximise the selected objective function and, in turn, the firm type. In particular, like in the static analysis, in each period t, appointed managers choose quantities and investments to maximise their objective function for a given industry configuration.

Following the previous notation Π^*_{ij} are the equilibrium profits of firm $i \in \{P, E\}$ when matched with firm $j \in \{P, E\}$. In practical terms, the duopoly can be formed between two P firms, 2 E firms, or a mix of both. If firm i is of type P, it earns profits Π^*_{PP} when matched with another P type and profits Π^*_{PE} when matched with an E type. Similarly, if firm j is of type E, it earns profits Π^*_{EP} or Π^*_{EE} when matched with a competitor of type P or E, respectively. For each firm type at t, the probability of being paired with a type E competitor is $f(t)$ and with a type P competitor is $1 - f(t)$. The probability of encountering a type E competitor $f(t)$ is equivalent to the proportion of managers adopting the E strategy in the population at time t. Likewise, the probability of encountering a type P competitor $1 - f(t)$ corresponds to the proportion of P-type managers in the population. Whenever the population of managers 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 the payoffs of their respective types according to Eq. (15) and Eq. (16). At each time period t, the expected profits for a firm whose manager opts for a P and E strategy are, respectively,

$$\begin{aligned} \mathbb{E}\left(\Pi^*_P(f)\right) &= f\Pi^*_{PE} + (1-f)\Pi^*_{PP}, \\ \mathbb{E}\left(\Pi^*_E(f)\right) &= f\Pi^*_{EE} + (1-f)\Pi^*_{EP}, \end{aligned} \tag{17}$$

where we omit the time argument for brevity. The fluctuation in the population of a specific type of manager depends on the comparison of expected profits outlined in Equation (17). This is governed by the following replicator dynamics (Weibull 1995; Antoci et al. 2021; Tang et al. 2021):

Table 1 The stage game

	Firm 2	
Firm 1	P	E
P	Π^*_{PP}, Π^*_{PP}	Π^*_{PE}, Π^*_{EP}
E	Π^*_{EP}, Π^*_{PE}	Π^*_{EE}, Π^*_{EE}

$$\dot{f} = f(1-f)[\mathbb{E}(\Pi_E^*(f)) - \mathbb{E}(\Pi_P^*(f))]. \tag{18}$$

We denote f^* as a stable steady state. According to (17), the industry is composed only by P firms ($f^* = 0$) if the P strategy is dominant, i.e., $\mathbb{E}(\Pi_P^*(f)) > \mathbb{E}(\Pi_E^*(f))$ for every f. Whenever the industry is composed only of P firms, $\mathbb{E}(\Pi_P^*(f)) > \mathbb{E}(\Pi_E^*(f))$ amounts to $\Pi_{PP}^* > \Pi_{EP}^*$, while if the industry is composed only of E firms, $\mathbb{E}(\Pi_P^*(f)) > \mathbb{E}(\Pi_E^*(f))$ corresponds to $\Pi_{EE}^* < \Pi_{PE}^*$. We will refer to this as the *P industry configuration*.

On the other hand, the industry is composed only of E firms (*E industry configuration*, $f^* = 1$) if the E strategy is dominant, i.e., for $\mathbb{E}(\Pi_P^*(f)) < \mathbb{E}(\Pi_E^*(f))$ for every f. When $f^* = 0$, this corresponds to $\Pi_{PP}^* < \Pi_{EP}^*$, and 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*.

5.2 Uniqueness of the *Mixed Industry Configuration*

Before examining the steady state equilibria in the industry, we need to verify how many mixed configurations are present in the industry. To do so, we need to verify that the differential of the expected profits $\mathbb{E}(\Pi_P^*(f)) - \mathbb{E}(\Pi_E^*(f))$ in Eq. (18) is linear in f, which implies that there exists a unique *Mixed industry configuration*, since they intersect at only one point. This is the standard method uniqueness of the mixed equilibrium can be seen, for instance, in Friedman (1996), p.5 (*Type 1*).[11] From Eq. (18), we may rewrite the differential of profits explicitly:

$$\mathbb{E}(\Pi_E^*(f)) - \mathbb{E}(\Pi_P^*(f)) = (1-f)(\Pi_{EP}^* - \Pi_{PP}^*) - f(\Pi_{EE}^* - \Pi_{PE}^*).$$

To ease the exposition, we define $\Delta\Pi \equiv \mathbb{E}(\Pi_P^*(f)) - \mathbb{E}(\Pi_E^*(f))$, which amounts to

$$\Delta\Pi = (1-f)\,a - fb, \tag{19}$$

where $a \equiv \Pi_{EP}^* - \Pi_{PP}^*$ and $b \equiv \Pi_{PE}^* - \Pi_{EE}^*$. First, the differential $\Delta\Pi$ is linear in f. Second, $\Delta\Pi\,(f=0) = a$ and $\Delta\Pi\,(f=1) = -b$. Third, we know, from the previous section, that $a<0$ for $f=0$ (the *P industry configuration*) and $b<0$ for $f=1$ (the E industry configuration). In turn, the Mixed industry configuration emerges whenever these two conditions do not hold, namely, $a>0$ and $b>0$. It follows that $\Delta\Pi$ crosses zero (i.e., the E and P's expected profits are equal) into a unique point, as in the example provided in Fig. 1. Therefore we may state

Lemma 1 *There exists a unique Mixed equilibrium.*

5.3 Steady State

We are now in a position to study the emergence of the steady state. Using Eq. (15) and Eq. (16), inequality $\Pi_{EE}^* > \Pi_{PE}^*$ can be written as

[11] The unicity of the mixed equilibrium is also discussed in Bomze (1986) and Friedman (1998).

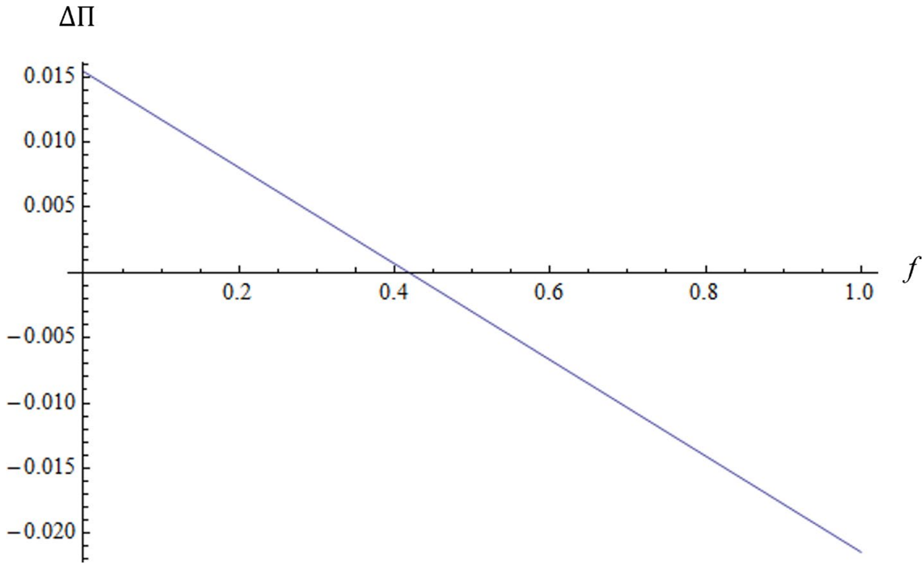


Fig. 1 Example of uniqueness of the mixed equilibrium in the plane $(f, \Delta\Pi)$. Other parameter values: μ=30, g=0.8, α=0.8, θ=0.8, and τ=3.7

$$\Pi^*_{EE} - \Pi^*_{PE} = \frac{1}{18}\theta\left[\tau(26 - 8\alpha g) + 9\theta - 8\mu(1 - \alpha g)\right] > 0, \tag{20}$$

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

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

In order the range $(\widehat{\tau}, \overline{\tau})$ to exist, the following lemma must hold.

Lemma 2 *An E industry configuration may emerge only if* $\alpha g > \frac{1}{4}$ and $\mu > \widehat{\mu}$, *where*

$$\widehat{\mu} \equiv \max\left\{\frac{\theta\left[43 - 4\alpha g(17 - 4\alpha g)\right]}{18}, \frac{\theta[47 - 2\alpha g(23 - 4\alpha g)]}{3(4\alpha g - 1)}\right\}.$$

Proof In Appendix.

Lemma 2 outlines the parameter values such that a $\Pi^*_{EE} > \Pi^*_{PE}$ can occur. Notice that this is one of the condition to obtain an *E industry configuration*. Hence, Lemma 2 implies that an industry composed of only *E* firms may emerge if and only if the willingness to pay of green consumers α or their proportion in the overall population g is sufficiently high: their product must be higher than $\frac{1}{4}$. This condition seems natural. After all, engaging in sustainable production requires a sufficiently high demand for sustainable products. In addition, the market size must be large enough, $\mu > \widehat{\mu}$. If these conditions do not hold, then an *E* configuration cannot exist, since $\widehat{\tau} > \overline{\tau}$. The intuition behind the necessity of a sufficiently large market is also related to the demand for sustainable products. A larger market size implies greater demand for both types of goods. This also spurs demand for firms of type E.

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.

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

Next, we turn on inequality $\Pi^*_{PP} - \Pi^*_{EP} > 0$. This may be written as

$$\Pi^*_{PP} - \Pi^*_{EP} = \frac{1}{18}\theta\left[8\mu - 8\alpha g(\mu - \theta(2-\alpha g)) - t(26 - 8\alpha g) - 17\theta\right] > 0, \tag{21}$$

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

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

and

$$\widehat{\tau} - \widetilde{\tau} = \frac{4\theta(1-\alpha g)^2}{13 - 4\alpha g} > 0. \tag{22}$$

Inequality Eq. (22) implies that, in the region $t \in (\widehat{\tau}, \overline{\tau})$, an E 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 P industry configuration is a stable steady state f^* in $\tau \in (0, \widetilde{\tau})$. 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 P or E type are identical. In particular, this occurs in the region $\tau \in (\widetilde{\tau}, \widehat{\tau})$, because, according to Eq. (22), 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

$$f^*_{mix} \equiv \frac{\theta\left(8\alpha^2 g^2 - 16\alpha g + 17\right) + 8\mu(\alpha g - 1) + \tau(26 - 8\alpha g)}{8\theta(\alpha g - 1)^2} \in (0,1), \tag{23}$$

for $\tau \in (\widetilde{\tau}, \widehat{\tau})$. 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. $E\,(f^* = 1)$ *for* $\tau \in (\widehat{\tau}, \overline{\tau})$;
2. *Mixed* $(f^* = f^*_{mix})$ *for* $\tau \in (\widetilde{\tau}, \widehat{\tau})$;
3. $P\,(f^* = 0)$ *for* $\tau \in (0, \widetilde{\tau})$.

Fig. 2 offers a graphical representation of the steady state industry configurations. The parameter values are chosen so that Assumption 1 and Assumption 2 hold. Naturally, an increase in the green consumers' willingess to pay for E products, as well as their proportion, helps entering in the region of the E industry configuration. The most interesting aspect of Proposition 2 is that an increase in the tax on emissions also pushes the diffusion of E firms. This effect is confirmed by differentiating the equilibrium share of E firms in the *Mixed industry configuration, yielding*

$$\frac{\partial f^*_{mix}}{\partial \tau} = \frac{13 - 4\alpha g}{4\theta(1 - \alpha g)^2} > 0. \tag{24}$$

Eq. (24) shows that an increase in the unit tax on emissions increases the share of E firms in the *Mixed industry configuration*. Thus a higher tax rate strategically favours E 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 E firms benefit from in terms of higher demand for green products. This result is consistent with the weak version of the Porter Hypothesis, since the increase in environmental regulation (the level of tax rate) pushes the emission reduction investment, leading firms to switch to E type and in turn toward the E industry configuration.

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

Corollary 3 *An increase in the proportion of green consumers* g*, their level of environmental awareness* α*, or the commitment of* E *firms to reducing their emissions* θ*, increases the size of the* E *region and the probability that an* E *type will be chosen.*

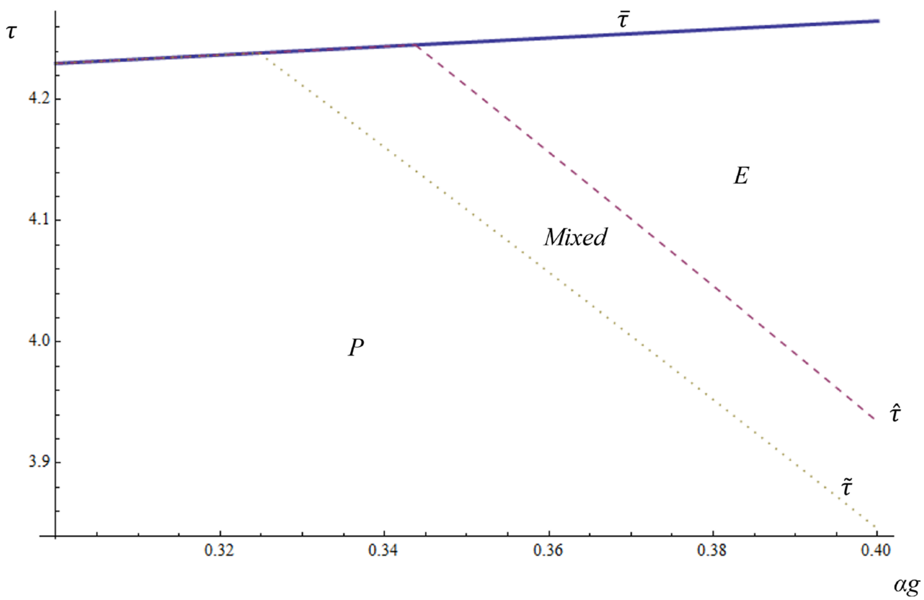


Fig. 2 Steady state industry configurations in the plane $(\alpha g, \tau)$. Other parameter values: μ=20, θ=0.7

Proof In Appendix.

The results in Corollary 3 indicate that an increase in the demand of green products, prompted by the share of green consumers or their sensitivity, increases the profitability of choosing an E type. In addition, the demand for green products is also driven by the commitment of the E firm in emission reduction abatement. Together with Proposition 2, the results of Corollary 3 clarify the role played by green consumers in the diffusion of E firms and the strategic role of the tax on emissions in increasing the competitive advantage of E firms by indirectly pushing the demand for green products.

The next corollary confirms the results in Corollary 3 by studying how changes in the parameter values affect the probability that firms choose an E-type manager in the *Mixed industry configuration*.

Corollary 4 *An increase in the proportion of green consumers* g, *in their level of environmental awareness* α, *or the commitment of* E *firms to reducing their emissions* θ, *increases the proportion of* E *firms in the Mixed industry configuration*.

Proof In Appendix.

Corollary 4 essentially states that an increase in demand for sustainable goods leads to greater adoption of sustainable production in the *Mixed industry configuration*. Additionally, the commitment of E firms to reducing emissions increases demand, which in turn encourages the switch towards the E strategy.

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

Corollary 5 *An increase in market size increases both the size of the* P *region and the probability that a* P *strategy will be chosen*.

Proof In Appendix.

Corollary 5 shows that, as market size increases, the demand advantage gained by E firms becomes relatively smaller, all else being equal, including the cost of commitment to reducing emissions.

5.4 Stability Analysis

After finding the steady states, the next step is to study the stability of the dynamical system. To do so, we rely again on Friedman (1996) and on the analysis of the differential of expected profits. Accordingly, the instability of the mixed equilibrium can be determined by considering the slope of Eq. (19) with respect to f. This is

$$\frac{\partial \Delta \Pi}{\partial f} = -(a+b) < 0.$$

It follows

Corollary 6 *Suppose the mixed equilibrium exists. Then, the dynamical system exhibits a stable mixed equilibrium. In particular, the E and P industry configurations are locally unstable, while the Mixed industry configuration is stable.*

Fig. 3 depicts the stability of the Mixed industry configuration by extending the example in Fig. 1. Hence, by Corollary 6, f^*_{mix} is the level of *f* such that $\Delta\Pi = 0$ and it is attractive.

Fig. 3 shows that, when the initial conditions of the economy are in the neighbourhood of the *P* industry configuration, the industry configuration spontaneously moves towards the Mixed one, this due to the fact that *P* is repulsive. At the same time, once reached the *E industry configuration* at f^*_{mix}, there are no spontaneous incentives to switch to another industry configuration, since f^*_{mix} is attractive.

Finally, it is important to note that, according to Equation Eq. (24), Corollary 3, 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 *P* firms to one with only *E* firms, encompassing all possible mixed combinations in between.

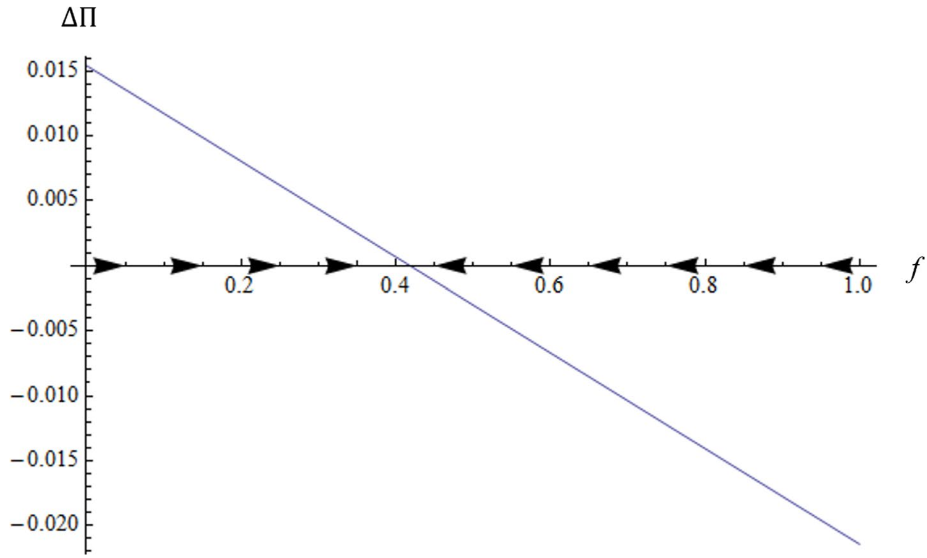


Fig. 3 Example of stability of the mixed equilibrium in the plane $(f, \Delta\Pi)$ Other parameter values $\mu = 30$ $\mu = 30$, $g = 0.8$, $\alpha = 0.8$, $\theta = 0.8$, and $\tau = 3.7$

6 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 E 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 (a *P 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 *E 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 E 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:

$$W = TIP + CS_g + CS_b + T - ED. \tag{25}$$

In (25), "Total industry profits" TIP amounts to

$$TIP = 2\mathbb{E}\left(\Pi^*\left(f^*_{mix}\right)\right),$$

where $\mathbb{E}\left(\Pi^*\left(f^*_{mix}\right)\right) = \mathbb{E}\left(\Pi^*_E\left(f^*\right)\right) = \mathbb{E}\left(\Pi^*_P\left(f^*\right)\right)$. This is because, in the *Mixed* industry configurations, the expected profits of an E or P type are equivalent. Furthermore, tax revenue corresponds to

$$T = \tau\left[2f^*(x^*_P(f^*) - z^*_P) + 2(1-f^*)(x^*_E(f^*) - z^*_E)\right], \tag{26}$$

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

$$ED = \left[2f^*(x^*_P(f^*) - z^*_P) + 2(1-f^*)(x^*_E(f^*) - z^*_E)\right]^2. \tag{27}$$

In what follows, we describe the effects of variations in α, g, θ, and τ on social welfare and its components through numerical simulation.

We proceed as follows, First, we set the following paramenter values: μ=30 and g=0.8, α=0.8, θ=0.8, and τ=3.7. These values ensure that Assumption 1 and Assumption 2 hold. Results are qualitatively similar using different parameter values, provided the aforementioned restrictions hold. Once establised these baseline values, we vary each parameter separately. Each parameter range of variation depends endogenously on the existence of the *Mixed industry configuration*: more formally, following point 2 of Proposition 2, in each range condition $\tau \in (\widetilde{\tau}, \widehat{\tau})$ holds.

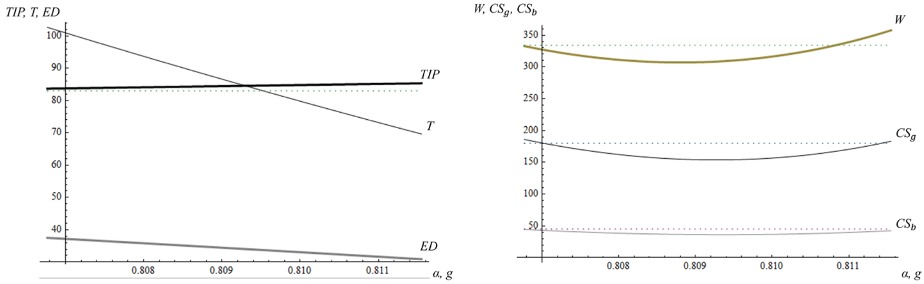
In Panel (a) of each figure, we illustrate how *TIP*, *ED*, and *T* respond to changes in the parameter values. Moreover, a horizontal dotted line is included to help the reader seeing the differences between low and high parameter values. In Panel (b) of each figure, we examine the effects on the consumer 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 Eq. (24) and Corollary 4, an increase in τ and g, α, θ, respectively, results in an increase in the share of E firms in the *Mixed industry configuration*. The parameter ranges considered in the analysis below span from an industry configuration with only P firms to one with only E firms, encompassing all possible mixed combinations in between.

6.1 Variation in the Share of Green Consumers/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. 4a, environmental damage and tax revenue decrease with an increase in consumers' environmental concern. This is natural to expect, considering that, as per Corollary 3, an increase in g or α leads to a higher proportion of E firms, which abate pollution more effectively than P firms. The consequence of a higher proportion of E 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 E firms is higher than that of P 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. 4b: 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 E 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 E firms appears to be the social optimum.



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

Fig. 4 Changes of social welfare and its components following a change in the proportion of green consumers g or in their environmental concern α. The dotted lines are horizontal. Other paramenter values: $\mu=30$, $\theta=0.8$, $\tau=3.7$

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 equilibrium prices and quantities with respect to a change in the share of E firms, namely,

$$\frac{\partial p^*_{k\omega}}{\partial f} = \frac{\partial x^*_{k\omega}}{\partial f} = \frac{2\theta(1-\alpha g)}{3} > 0, \text{for every } k \in \{P, E\}, \omega \in \{g, b\}.$$

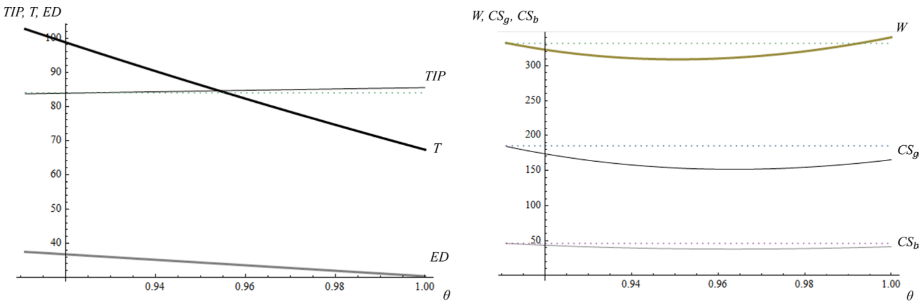
All equilibrium prices and quantities increase with an increase in E firms, indicating contrasting competitive forces. A lower level of competition between firms of different types occurs when the proportion of firms of each type is similar because, in this case, the number of vertically differentiated goods is the highest. However, with many P or E 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 P 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.

6.2 Variation in the Emission Internalisation and Tax Rate

Figures 5 and 6 illustrate the changes in social welfare and its components due to variations in E firms' environmental concern and emissions tax. Eq. (24) and Corollary 3 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.

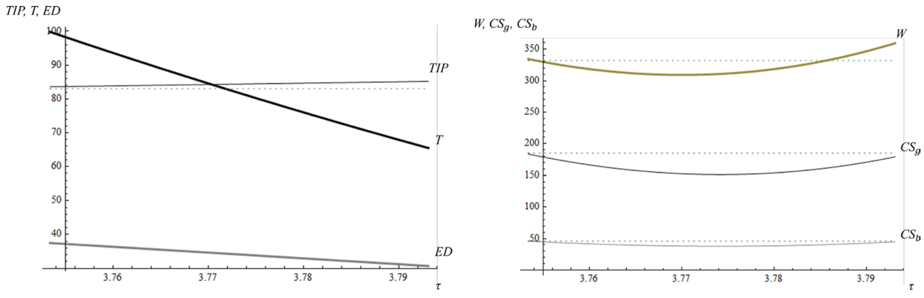
However, there is an important difference in the variation of E's environmental commitment compared to τ, g, and α: indeed, θ is determined by firms, and Fig. 5a has shown that there is a private incentive to increase environmental concern because of its positive



(a) TIP, environmental damage, tax revenue.

(b) Consumer suprlus and social welfare

Fig. 5 Changes of social welfare and its components following a change in the E's level of emission internalisation θ. The dotted lines are horizontal. Other paramenter values: $\mu=30$, $g=0.8$, $\alpha=0.8$, $\tau=3.7$



(a) TIP, environmental damage, tax revenue.

(b) Consumer suprlus and social welfare

Fig. 6 Changes of social welfare and its components following a change in the tax on emissions τ. The dotted lines are horizontal. Other paramenter values: $\mu=30$, $g=0.8$, $\alpha=0.8$, $\theta=0.8$

(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. Consistent with the findings of Proposition 2, the results shown in Fig. 6 support the Porter Hypothesis: as the tax rate increases, so does the technoogy investment in emission reduction, and eventually industry profits.

7 Extensions

In this section, we modify some of the assumptions of the baseline model to evaluate the robustness of our results.

7.1 Cleaner Production

So far, we have assumed that the emission reduction technology was of end-of-pipe type: while these technologies help to reduce the release of pollutants into the atmosphere, they cannot completely eliminate environmental damage. This is because they work by reducing emissions at the final stage of the production process.

In this section we extend our results by including a specific class of process-integrated abatement technologies in our methodology. Examples of such practices are: the implementation of systems in the paper industry to recycle water and chemicals within the production process (Ayres and Ayres 1996), the adoption of low-emission fermentation technologies in the chemical industry (Hartman et al. 1997), or the use of biomass instead of coal in power generation (Sijm et al. 2005). In what follows we show that the evolutionary equilibrium yields qualitatively similar results as the baseline case.

When studying an abatement technology that modifies the production process, the cost of abatement is assumed to depend on the level of production (see for example Subramanian et al. 2007; Mantovani et al. 2017; Anand and Giraud-Carrier 2020; Lambertini et al. 2020; Iannucci and Tampieri 2024) and can be modelled as:

$$CL_k = x_k \frac{z_k^2}{2}, \tag{28}$$

for each $k \in \{E, P\}$. Given that the unit emission reduction is $x_k z_k$, the emissions resulting from the new technology are:

$$e_k^{CL} = x_k(1 - z_k),$$

where subscript *CL* stands for “cleaner production”.

With the implementation of process-integrated abatement technology, profit maximisation with respect to x_k and z_k yields the following equilibrium profits:[12]

$$\begin{aligned}
\Pi_{PP}^{CL} &= \frac{1}{36}\left(2\mu + \tau^2 - 2\tau\right)\left(2\mu + \tau^2 - 2\tau\right), \\
\Pi_{PE}^{CL} &= \frac{1}{36}\left[2\mu + \tau^2 - 2(\theta + 1)\tau - \theta(2\alpha g + \theta - 2)\right]^2, \\
\Pi_{EP}^{CL} &= \frac{1}{36}\left[2\theta(2\alpha g + \theta - 2) + 2\mu + \tau^2 - 2(1 - 2\theta)\tau\right]^2, \\
\Pi_{EE}^{CL} &= \frac{1}{36}\left[\theta(2\alpha g + \theta - 2) + 2\mu + \tau^2 - 2(1 - \theta)\tau\right]^2.
\end{aligned}$$

To evaluate meaningful results, we restrict the analisys to a parameter range such that profits of all industry configurations are positive. In particular, $\Pi_{PP}^* > 0$ for $\mu > \mu_{PP}$, $\Pi_{PE}^* > 0$ for $\mu > \mu_{PE}$, $\Pi_{EP}^* > 0$ for $\mu > \mu_{EP}$ and $\Pi_{EE}^* > 0$ for $\mu > \mu_{EE}$, where

$$\begin{aligned}
\mu_{PP} &\equiv \frac{1}{2}(2 - \tau)\tau, \\
\mu_{PE} &\equiv \frac{1}{2}\theta(2\alpha g + \theta - 2) - \frac{\tau^2}{2} + (\theta + 1)\tau, \\
\mu_{EP} &\equiv -\theta(2\alpha g + \theta - 2) - \frac{\tau^2}{2} - 2\theta\tau + \tau, \\
\mu_{EE} &\equiv -\frac{1}{2}\theta(2\alpha g + \theta - 2) - \frac{\tau^2}{2} - \theta\tau + \tau.
\end{aligned}$$

For convenience, we thus define

$$\mu^{CL} \equiv \max\left\{\mu_{PP}, \mu_{PE}, \mu_{EP}, \mu_{EE}\right\},$$

and we assume

Assumption 3 *Let* $\mu > \mu^{CL}$.

Similar to the baseline analysis, a sufficiently large market ensures that all duopoly configurations can emerge in equilibrium. The intuition is that a large market size ensures high demand in every possible situation, whether production is sustainable or not, and thus the

[12] The computation has been omitted for brevity.

emergence of all possible configurations. We are now equipped to study the pure strategy equilibria: inequality $\pi_{EE}^{CL} > \pi_{PE}^{CL}$ can be written as

$$\frac{1}{9}\theta[2\mu + (\tau - 2)\tau)(2\alpha g + \theta + 2\tau - 2] > 0,$$

for $\tau > \tau^{CL}$, where

$$\tau^{CL} \equiv 1 - g\alpha - \frac{\theta}{2},$$

while inequality $\pi_{PP}^{CL} > \pi_{EP}^{CL}$ can be written as

$$-\frac{1}{9}\theta(2\alpha g + \theta + 2t - 2)\left(\theta(2\alpha g + \theta - 2) + 2\mu + t^2 + 2(\theta - 1)t\right) > 0,$$

for $\tau > \tau^{CL}$. Accordingly, $\tau > \tau^{CL}$ ensures the dominance of the *E* strategy, while $\tau < \tau^{CL}$ ensures the dominance of the *P* strategy. It follows that

Proposition 3 *Let Assumption 3 hold. The industry configuration is*

1. $E\,(f^* = 1)$ *for* $\tau > \tau^{CL}$;
2. $P\,(f^* = 0)$ *for* $\tau < \tau^{CL}$.

Notice that the equilibrium threshold in Proposition 3, τ^{CL} is not necessarily larger than zero. Indeed, its positivity requires:

$$\theta < 2 - 2\alpha g.$$

In words, as the share of green consumers, their sensitivity to environment or the emission internalisation of *E* firms increases, so the unique admissible equilibrium is the *E industry configuration*. Compared to the baseline result, this may be due to the extra strength of cleaner production in abating emissions, and hence the fiscal cost. This technology gives a competitive advantage to *E* firms with an increase in environmentally concerned consumers or in their voluntary emission reductions.

Finally, note that Proposition 3 leaves no space to a *Mixed industry configuration*. This may be confirmed by the following analysis. Define $f^{CL}(t)$ as the probability of being paired with a type *E* competitor when the emission reduction technology is of cleaner type, and where in what follows we omit time argument. Hence, the expected profits are

$$\begin{aligned}\mathbb{E}\left[\pi_P^{CL}\left(f^{CL}\right)\right] &= f\pi_{PE}^{CL} + (1-f)\pi_{PP}^{CL},\\ \mathbb{E}\left[\pi_E^{CL}\left(f^{CL}\right)\right] &= f\pi_{EE}^{CL} + (1-f)\pi_{EP}^{CL},\end{aligned} \tag{29}$$

from which we may infer the replicator dynamics:

$$\dot{f}^{CL} = f^{CL}(1 - f^{CL}) \left[\mathbb{E}\left(\pi_P^{CL}\left(f^{CL}\right)\right) - \mathbb{E}\left(\pi_E^{CL}\left(f^{CL}\right)\right)\right]. \tag{30}$$

Following the same procedure as in the baseline analysis, $\mathbb{E}\pi_P^{CL}(f^{CL}) = \mathbb{E}\pi_E^{CL}(f^{CL})$ requires

$$f_{mix}^{CL} \equiv \frac{\theta(2 - 2\alpha g - \theta) + 2\tau(1-\theta) - 2\mu - \tau^2}{\theta(2 - 2\alpha g - \theta - 2\tau)}, \tag{31}$$

which is not admissible as a mixed equilibrium, as shown in the following result.

Corollary 7 *Let Assumption 3 hold, then is not an admissible Mixed equilibrium configuration*: $f_{mix}^{CL} \notin [0, 1]$.

Corollary 7 shows that the proportion of firms for which the expected payoffs of choosing P or E are equal never lies between zero and one. This confirms that there is not a mixed equilibrium in this dynamical system.

7.2 Alternative Dynamics

As stressed in the presentation of the analysis, our model is built on the framework by Droste et al. (2002). We are going to use a different model to evaluate the robustness of our analysis.

To do so, we set aside the managers' matching in a duopoly and we rely on (Buccella et al. 2023). In terms of evolutionary dynamics, the main differences here are two. First, (Buccella et al. 2023) assume that an exogenous share of firm δ evaluate whether to change their type, given the depletion of some machineries, whereas we assume that an exogenous share of managers δ observes (through market analysis) the change in the share of green consumers and evaluate to change their type accordingly. The second difference is that (Buccella et al. 2023) study an oligopoly, while we focus on a duopoly.[13]

Following (Buccella et al. 2023), we consider discrete time. First, we define as $m \in [0, 2]$ the number of *E* firms in the industry. Second, we define, by Proposition 1, a more general version of equilibrium profits in the static setting, as functions of *m*:

$$\Pi_P(m) = \frac{2[m\theta(1-\alpha g) + \mu]^2 - 4\theta m\tau(1-\alpha g) + 11\tau^2 - 4\mu\tau}{18}, \tag{32}$$

$$\begin{aligned}\Pi_E(m) = &\frac{\theta^2 \left\{2m^2(1-\alpha g)^2 - 12m(1-\alpha g)^2 + 9\left[3 - 2\alpha g(2-\alpha g)\right]\right\}}{18} + \\ &\frac{2\theta\tau\left[3(5-2\alpha g) - 2m(1-\alpha g)\right] - 4\theta\mu(1-\alpha g)(3-m)}{18} + \\ &\frac{2\mu^2 + 11\tau^2 - 4\mu\tau}{18},\end{aligned} \tag{33}$$

[13] An oligopoly with $N>2$ firms can be analysed in Droste et al. (2002) by modifying the matching mechanism, at the cost of analytical tractability. See for example Kopel and Lamantia (2018) or Iannucci and Tampieri (2023).

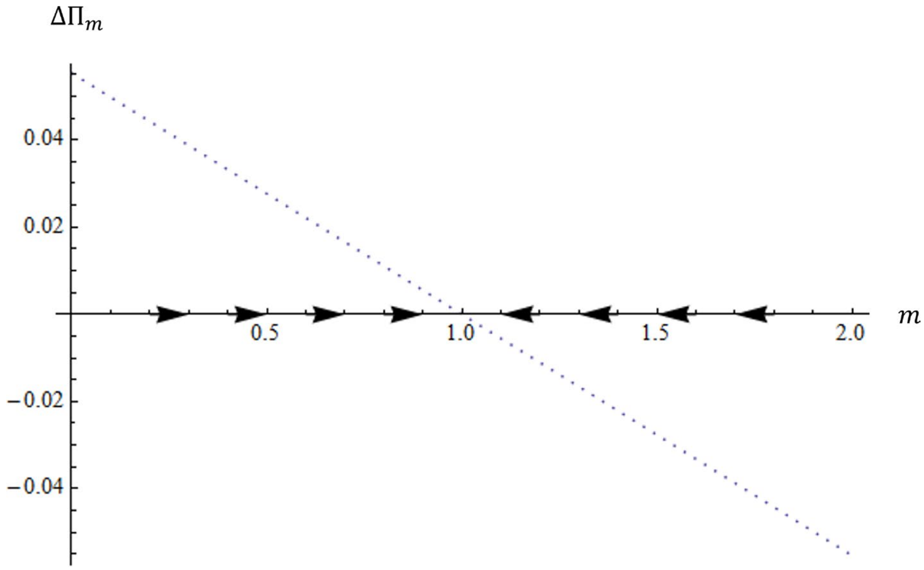


Fig. 7 Example of stability in the plane $(m, \Delta\Pi_m)$. Other parameter values:μ=30, g=0.8, α=0.8, θ=0.8, and τ=5.45

By substituting m=0, m=2 and m=1 into Eq. (32) and Section 7.2, one obtains the equilibrium profits in Eq. (15) and Eq. (16). Finally, following Buccella et al. (Buccella et al. 2023), we introduce the index describing the incentive to change the status time by time, i.e. the profit differential between P and E. This index is given by the following expression:

$$\Delta\Pi_m = \Pi_E(m) - \Pi_P(m), \tag{34}$$

and $\Delta\Pi_1 = 0$ for m=1 and

$$\tau = \widehat{\tau}_\delta \equiv \frac{4\mu\,(1-\alpha g) + \theta\left[4m(\alpha g-1)^2 - (N+1)(3-2\alpha g(2-\alpha g))\right]}{2(N+3-2\alpha g)}.$$

We now need to verify whether the mixed equilibrium $\Delta\Pi_m = 0$ is stable in this dynamic system. To do so, we will again rely on Friedman (1996) by studying the sign of the differential of profits with respect to the number of E firms, m, here in a discrete context. It is easy to verify that

$$\Delta\Pi_0 - \Delta\Pi_1 = \Delta\Pi_1 - \Delta\Pi_2 = \frac{2}{3}\theta^2(1-\alpha g)^2 > 0,$$

indicating a stable *Mixed industry configuration* (See Fig. 7, for example). Hence, the equilibrium properties with a different dynamic sistem appear to be consistent with those in the baseline analysis.

8 Concluding Remarks

We have analysed the role played by consumers' environmental concern in the transition towards sustainable production. In a market where a share of consumers is environmentally conscious, we determine the steady-state equilibrium where firms choose to adopt or not ECSR activities, which consist in the internalisation of a firm's emission reduction. First, we have studied the static oligopoly, from which we have elicited the firm's equilibrium behaviour in the market stage. With the introduction of the evolutionary setting, we have included the static results as the competition behaviour in each time period, through which firms form expectations of profits and then choose their type (either P or E) in the dynamic game.

We have shown that, intuitively, an increase in the share of green consumers and in their willingness to pay for ECSR products helps the transition towards a population of all ECSR firms. An increase in the emission tax rate favours the transision, in line with the weaker version of the Porter Hypothesis. In social welfare analysis, our results has shown 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. This policy approach would provide incentives for firms to voluntarily switch to sustainable production technologies that internalise their environmental impacts, thereby easing the transition to sustainable production.

A possible limitation of the present analysis is the fact that the proportion of green consumers is taken as exogenous. With this assumption, we were able to evaluate the industry configuration formation for different degrees of their proportion, but since the choice of consumers' type is not endogenously modelled, they not actively contribute to the equilibrium formation. A possible modelling of consumer's choice might consider their advantage in switching from brown to green type, or vice versa. In turn, firms would evaluate the consumers' type choice in deciding theirs. The determination of an evolutionary equilibrium determined by the combined type choice of consumers and firms could be an interesting avenue for future research.

Appendix

Proof of Corollary 2

First, we verify the conditions with respect to τ such that the static equilibrium quantities and investments in emission reduction technology are positive. For $i = j = P$,

$$x^*_{PP} = \frac{\mu - \tau}{3} > 0, \qquad \text{for } \tau < \tau_{x_{PP}} \equiv \mu,$$

while $z_{PP}^{*}=\tau>0$ always. For $i=j=E$,

$$x_{EE}^{*}=\frac{\mu-\tau-\theta\left(1-\alpha g\right)}{3}>0,\qquad \text{for } \tau<\tau_{x_{EE}}\equiv\mu-\theta\left(1-\alpha g\right),$$

while $z_{EP}^{*}=\tau+\theta>0$ always. For i=P and j=E,

$$x_{PE}^{*}=\frac{\mu-\tau+\theta\left(1-\alpha g\right)}{3}>0,\qquad \text{for } \tau<\tau_{x_{PE}}\equiv\mu+\theta\left(1-\alpha g\right),$$

while

$$x_{EP}^{*}=\frac{\mu-\tau-2\theta\left(1-\alpha g\right))}{3}>0,\qquad \text{for } \tau<\tau_{x_{EP}}\equiv\mu-2\theta\left(1-\alpha g\right).$$

Again, $z_{PE}^{*}=\tau$ and $z_{EP}^{*}=\tau+\theta$. Next, we evaluate which conditions are sufficient for positivity. Given that $\alpha g\leq 1$, then a quick glance between the four thresholds reveals that $\tau_{x_{EP}}$ is a sufficient condition such that the equilibrium outputs are always positive.

We now turn to evaluate the conditions over τ such that equilibrium emissions are positive. For $i=j=P$,

$$e_{PP}^{*}=\frac{\mu-4\tau}{3}>0,\qquad \text{for } \tau<\tau_{5}\equiv\frac{\mu}{4}.$$

For $i=j=E$,

$$e_{EE}^{*}=\frac{\mu-4\tau-\theta\left(4-\alpha g\right)}{3}>0,\qquad \text{for } \tau<\tau_{e_{EE}}\equiv\frac{\mu-\theta\left(4-\alpha g\right)}{4}.$$

For i=P and j=E,

$$e_{PE}^{*}=\frac{\mu-4\tau+\theta\left(1-\alpha g\right)}{3}>0,\qquad \text{for } \tau<\tau_{e_{PE}}\equiv\frac{\mu+\theta\left(1-\alpha g\right)}{4},$$

$$e_{EP}^{*}=\frac{\mu-4\tau-\theta(5-2\alpha g)}{3}>0,\qquad \text{for } \tau<\tau_{e_{EP}}\equiv\frac{\mu-\theta\left(5-2\alpha g\right)}{4}.$$

Next, we evaluate which conditions are sufficient so that equilibrium emissions are positive. The first threshold, $\tau_{e_{PP}}$ is clearly higher than $\tau_{e_{EE}}$. Comparing $\tau_{e_{EE}}$ and $\tau_{e_{PE}}$:

$$\tau_{e_{EE}}-\tau_{e_{PE}}=\frac{\mu-\theta\left(4-\alpha g\right)}{4}-\frac{\mu+\theta\left(1-\alpha g\right)}{4}=\frac{\theta\left(5-2\alpha g\right)}{4}>0,$$

so that $\tau_{e_{EE}}<\tau_{e_{PE}}$ always, which allows to exclude $\tau_{e_{PE}}$.Comparing $\tau_{e_{EE}}$ with $\tau_{e_{EP}}$, one gets

$$\tau_{e_{EE}} - \tau_{e_{EP}} = \frac{\mu - \theta\,(4 - \alpha g)}{4} - \frac{\mu - \theta\,(5 - 2\alpha g)}{4} = \frac{\theta\,(1 - g\alpha)}{4} \geq 0.$$

so that $\tau < \tau_{e_{EP}}$ is a sufficient condition such that equilibrium emissions are positive.

In order to verify both output ad emissions, then we must compare $\tau_{x_{EP}}$ and $\tau_{e_{EP}}$, which yields

$$\tau_{x_{EP}} - \tau_{e_{EP}} = \mu - 2\theta\,(1 - \alpha g) - \frac{\mu - \theta\,(5 - 2\alpha g)}{4} = \frac{3\,[\mu + g\alpha - \theta\,(1 - g\alpha)]}{4} > 0,$$

for

$$\mu > \theta\,(1 - g\alpha) - g\alpha,$$

and vice versa. Summarising we get:

$$\tau < \overline{\tau} \equiv \min\left\{\mu - 2\theta\,(1 - \alpha g)\,,\, \frac{\mu - \theta\,(5 - 2\alpha g)}{4}\right\}.$$

□

Proof of Lemma 2

In order an industry composed of only E firm ay emerge, inequality $\Pi^*_{EE} > \Pi^*_{PE}$ must be admissible. The inequality holds if

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

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

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

By Corollary 2, then τ may be higher than $\widehat{\tau}$ only if $\widehat{\tau} < \overline{\tau}$. Since $\overline{\tau} = \min\{\tau_{x_{EP}}, \tau_{e_{EP}}\}$ takes the minimum of two values, this requires two sufficient conditions. The first condition is $\widehat{\tau} < \tau_{x_{EP}}$, that is,

$$\frac{18\mu - \theta\,[43 - 4\alpha g(17 - 4\alpha g)]}{26 - 8\alpha g} > 0,$$

which occurs if

$$\mu > \frac{\theta\,[43 - 4\alpha g(17 - 4\alpha g)]}{18}.$$

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

$$\frac{3\mu(4\alpha g - 1) - \theta[47 - 2\alpha g(23 - 4\alpha g)]}{52 - 16\alpha g} > 0,$$

and occurs if

$$\mu > \frac{\theta[47 - 2\alpha g(23 - 4\alpha g)]}{3(4\alpha g - 1)}.$$

□

Proof of Corollary 3

Differentiating $\widehat{\tau}$ and $\widetilde{\tau}$ with respect to α and g yields, respectively,

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

$$\frac{\partial \widetilde{\tau}}{\partial \alpha} = \frac{\partial \widetilde{\tau}}{\partial g} = \frac{2g\left[\theta\left(8\alpha^2 g^2 - 52\alpha g + 35\right) - 18\mu\right]}{(13 - 4\alpha g)^2} < 0, \text{for } \mu > \widehat{\mu}.$$

Differentiating $\widehat{\tau}$ and $\widetilde{\tau}$ with respect to θ yields, respectively,

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

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

□

Proof of Corollary 4

We study the changes in the probability that firms choose a manager of type E in the *Mixed industry configuration*, namely, f^*_{mix}. Differentiating f^*_{mix} with respect to α, g, θ and μ yields, respectively,

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

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

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

Proof of Corollary 5

Differentiating $\widehat{\tau}$ and $\widetilde{\tau}$ with respect to μ yields, respectively,

$$\frac{\partial \widehat{\tau}}{\partial \mu} = \frac{\partial \widetilde{\tau}}{\partial \mu} = \frac{4-4\alpha g}{13-4\alpha g} > 0.$$

□

Proof of Corollary 7

In what follows, we prove that f^{CL}_{mix} is not a mixed equilibrium ($f^{CL}_{mix} \notin [0,1]$ for the relevant parameter range, $\mu > \mu^{CL}$. Consider first $f^{CL}_{mix} > 0$. This requires

$$\frac{\theta(2-2\alpha g-\theta)+2\tau(1-\theta)-2\mu-\tau^2}{\theta(2-2\alpha g-\theta-2\tau)} > 0. \tag{35}$$

The denominator is positive for $\tau > \tau^{CL}$, so that Eq. (35) is positive if the numerator is positive, which occurs if $\mu > \mu_{EE}$. It follows that, if $\tau < \tau^{CL}$, positivity would require $\mu < \mu_{EE}$, which is false by Assumption 3. Next we verify the conditions under which $f^{CL}_{mix} < 0$, i.e.,

$$\frac{\theta(2-2\alpha g-\theta)+2\tau(1-\theta)-2\mu-\tau^2}{\theta(2-2\alpha g-\theta-2\tau)} < 1. \tag{36}$$

If $\tau > \tau^{CL}$, condition Eq. (36) would require $\mu < \mu_{PP}$, which is false by Assumption 3. If $\tau < \tau^{CL}$, we already know that positivity is not respected. Therefore, if Assumption 3, then f^{CL}_{mix} is not an admissible mixed equilibrium.

□

Acknowledgements We thank Gianluca Iannucci, Fabio Lamantia, Domenico Menicucci, the Editors Simone Borghesi and Luca Gori and two anonymous Reviewers for comments that led to substantial improvements in the paper. An older version of the paper was part of the MSc dissertation of Aissa. The usual disclaimer applies.

Funding Open access funding provided by Università degli Studi di Modena e Reggio Emilia within the CRUI-CARE Agreement.

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