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Public Pro-Environmental Behaviour and the Transition to Environmentalism*

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Abstract

We analyse the effect of public pro-environmental behaviour (PEB) on sustainable consumption choices in the economy. We argue that observing individuals who are actively engaged in improving the quality of the environment encourages others to imitate them. We adopt a model of social learning in which individuals interact in pairs and choose their type based on different environmental attitudes and purchasing decisions. In our framework, public PEB increases the likelihood that individuals will meet others who openly engage in PEB, which affects their self-image and their concern for the environment. Finally, we assess how public PEB interacts with pro-environmental policies. We find that public PEB induces the population to adopt sustainable consumption and increases the effectiveness of related policies.

JEL Codes: C73, D91, Q56.

Keywords: Random pairing, Public pro-environmental behaviour, Self-image.

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1 Introduction

Public pro-environmental behaviour (PEB) includes actions aimed at promoting environmental protection and sustainability in the public sphere (Burn, 1991 and Stern, 2000, among others). These actions can include taking part in protests, signing petitions, donating to environmental causes and joining environmental organisations, or include sharing resources, volunteering for environmental causes and advocating for environmental policies. There is substantial evidence of the growing increase of public PEB. Examples are volunteer beach cleanups (Jorgensen et al., 2021, Konecny et al., 2018, Ehl et al., 2017, among others), participation in neighbourhood park management (Mohapatra and Mohamed, 2013) or planting trees (Watkins et al., 2018 and Fisher et al., 2015, among others).

The environmental literature has extensively studied PEB, by mainly addressing its determinants (see Gifford and Nilsson, 2014 and Nilsson et al., 2017 and Li et al., 2019 for recent reviews) while a bulk of works focused on the different features between public or private PEB. Yang and Wilson (2023) introduce demographic, political, socioeconomic and attitudinal variables to explain PEB. Thoyre (2011) find that social capital may turn out to be a determinant of PEB. Hadler and Haller (2011, 2013) study the difference in public and private PEB across nations, finding that the former is similar across countries, while latter is affected by the local context. Some studies analysed gender differences in public and private PEB (Hunter et al., 2004, Briscoe et al., 2019).

In this paper we are interested on the possible social dynamics triggered by public PEB. The idea is that exposing PEB to others induces a re-evaluation of their personal social norms. In other words, individuals exerting effort to improve the environmental quality act as an "example" to imitate by others. For instance, having a walk in the local park and seeing individuals that voluntarily pick up someone else's litter may induce individuals to be more careful about littering or also push them to help in the cleanup process. Borrowing from social psychology (Bandura and Walters, 1977 and Bandura et al., 1986, among others), we argue that public PEB has a social learning effect that spurs others to change their behaviour toward the environment.

Based on that, we evaluate whether public PEB plays a role to guide the society toward sustainable consumption, and how it interacts with related policies. We build a model of social dynamics in which individuals of different types interact among each others, and the interaction affects their type choice (Durlauf and Young, 2001 and Bowles, 2003, among others). First, different types purchase a good based on different intrinsic environmental quality (either clean or dirty). By borrowing from social psychology (Kahneman and Tversky, 1979), we account for *similarity bias* in their social interaction: individuals prefer to meet with others with similar consumption preferences.

Second, individuals choose their attitude towards the environment: they may be indifferent to their environmental impact (*brown* types), they may feel a sense of dismal towards the human impact of the environment (*environmentally concerned* types), or they may exert voluntary effort to help the environment (*Greta Thunberg* types). Thus individuals may take into account their self-image towards the environment (Nyborg, 2003, among others) but differently according to their type.

In modelling the social interaction, we assume that public PEB increases the probability that individuals meet *Greta Thunberg* types, since they are publicly exposed in their effort. In particular, we consider two separate scenario. One in which all individuals are *Brown*, and PEB is only private. This should represent a social context in which environmental issues did not occur, and might be interpreted as the 50s in Western countries. Then, starting again from initial conditions close to the state where the vast majority of individuals are *Brown*, we assume that PEB becomes public.

Our results show that public PEB plays a crucial role to affect the attitude of the population towards the environment. In a scenario where PEB is only private, a population that is predominantly *Brown individuals* does not change. Also policy interventions to promote green consummerism, such as eco incentives, environmental awareness campaign or the help of local authorities towards environmental activists, are ineffective if PEB is only private. In contrast, the emergence of pubic PEB spurs the population to transit toward sustainable consumption, and makes the policies be effective.

The rest of the paper is organised as follows. Section 2 outlines some of the relevant literature linked to the paper. Section 3 develops the model, and Section 4 shows the results. Section 5 extends the baseline analysis by allowing that individuals may not behave in a fully rational way. Section 6 concludes, while all proofs can be found in the Appendix.

2 Related literature

The paper is mainly related to the theoretical literature that has studied the determinants of PEB. This topic has been analysed from different disciplines, in particular sociology, social psychology and economics. In the following, we will concentrate on the latter.

Economists have focused on the influence of external factors such as price and income when studying PEB (Gsottbauer and van den Bergh, 2011). Standard economic theory suggests that economic incentives are effective in encouraging individuals to protect to adopt PEB (Clark et al., 2003 and Heller and Vatn, 2017, among others).

In recent decades, however, economists have incorporated concepts from psychology into the standard utility framework, and social norms have been integrated as a key factor to affect behaviour (Elster, 2020). One concept that has been extensively considered and that we adopt here, is "self-image", which is often studied as a key factor influencing individual behaviour, particularly in the context of moral motivation and PEB. In Brekke et al. (2003), individuals derive utility not only from material consumption, but also from their self-image, which is linked to their perception of being a morally good person. The concept of self-image is linked to moral motivation: people engage in pro-environmental behaviour because it enhances their self-image as someone who acts according to ethical standards. This intrinsic motivation can explain why individuals may engage in PEB even in the absence of external incentives. Nyborg (2011) explores the idea of rational ignorance, where individuals deliberately avoid information about the negative environmental impact of their actions to protect their self-image.

In Benabou and Tirole (2011), behaviour depends on three main factors: intrinsic motivation, extrinsic motivation and reputation. Social norms influence choice through expected costs and reputational effects, which in turn can be explained by self-image concerns.

Czajkowski et al. (2017) examines the interplay between social norms, moral considerations and self-interest in determining pro-environmental behaviour, using household recycling as a case study. Self-image is discussed as a component of moral motivation, where individuals are influenced by their desire to see themselves and be seen by others as responsible and ethical. The authors suggest that increasing the visibility of pro-environmental actions can reinforce social norms and, consequently, positively affect self-image, and thus encourages more sustainable behaviour.

From a methodological point of view, our paper is related to the literature on evolutionary game theory to study how social norms in general evolve over time and their impact on economic behaviour (Gintis, 2014 and Young, 2015, among others). A seminal paper in this area is Sethi and Somanathan (1996), who investigate how social norms evolve in the context of common property resource use. They examine the conditions under which social norms that promote sustainable use of common property resources can emerge and become stable. In this analysis, the type of *enforcer* that sanctions individuals who overuse the common resource (*defector*) is important. In contrast to this work, our analysis does not focus on cooperation, defection or punishment, but on the spontaneous evolution of types based on social interaction.

Our analysis shares some features with Nyborg et al. (2006), who analyse how moral motivations influence green consumer behaviour and public policy. As in our paper, individuals can purchase either a green or a non-green product, and the analysis develops a dynamics that evaluates the equilibrium distribution of types. Consumption behaviour is also motivated by self-image concerns, but there is no social interaction between individuals, which consequently does not influence the purchasing decision.

Schumacher (2009) explores the relationship between environmentalism and environmental change, with a focus on the intergenerational dynamics that influence both. This analysis is interested in the evolution of preferences rather than purchasing decisions, although the aggregate preferences have an impact on pollution levels. The dynamics are also affected by the family of origin rather than social interactions.

More recently, Sartzetakis et al. (2023) investigate the interplay between social status, consumption, and environmental regulation. In particular, they assume that social status is acquired through the consumption of highly polluting goods. Thus, a regulatory measure that includes information provision aimed at moderating status-seeking overconsumption improves social welfare. In contrast to Sartzetakis et al. (2023), we disregard the effects of social status to focus on the role of self-image.

Compared to these papers based on evolutionary frameworks, the important difference of our paper is that they do not analyse public PEB and how this may affect purchase choices.

3 The model

3.1 *Clean* or *dirty* consumption

We study an economy in which individuals' consumption patterns are influenced by social interactions. There is a large population of n individuals. All members of the population purchase one unit of a homogeneous good getting, from this, a consumption benefit a.[1] While goods are identical in terms of features and quality, they may be produced through a *clean* or *dirty* production process, according to whether production is environmentally sustainable or not, respectively. We assume that the industry is perfectly competitive between firms using the same production process, but the price of the clean product, p_c, is higher to that of the dirty product, p_d, so that $p_c > p_d > 0$. The higher price of the clean product reflects the higher cost of producing a good with a low impact on the environment. In particular, we assume that both production processes, clean and dirty, have constant marginal costs k_c and k_d, respectively, with $k_c > k_d$.

We indicate the price differential as $\Delta p = p_c - p_d$. Finally, to exclude irrelevant cases, we assume that the benefit from consumption is always higher than prices, $a > p_c$.

3.2 Population types

The members of the population may differ by types. A share $\pi_b \in [0, 1]$ of individuals may be *brown* (B) and buy a dirty good. Alternatively, individuals may be *green* and buy a clean good. Green consumers can be of two subtypes: there is a share $\pi_e \in [0, 1]$ of *environmentally concerned* (E), who are worried about the environment and therefore have an emotional cost-benefit approach to environmental issues, and a share $\pi_g \in [0, 1]$ of *Greta-Thunberg green* (G), who make efforts to reduce human impact on the planet. It follows that $\pi_b + \pi_e + \pi_g = 1$.

Individuals of type G may spend their free time picking up litter, campaigning against polluting practices, teaching children about ecology at school, and so on. In other words, they adopt a *pro-environmental behaviour*, or PEB. Depending on whether these activities are undertaken privately or publicly, we will refer to them as *private* or *public* PEB.

[1]The framework can be extended by considering individuals who do not buy anything, but this would complicate the analysis without adding much to the scope of the paper.

3.3 Payoffs

Each type payoff is given by the consumption benefit a, identical for both good types, minus the price of the good, either p_c or p_d. In addition, two psychological features affect types: similarity bias and self-image.

3.3.1 Similarity bias

When two B or green (either E or G) individuals meet (see below), they enjoy finding someone who focuses on their same issues and receive a benefit $s > 0$. This benefit represents what sociologists and social psychologists call “similarity bias” (see Tversky and Kahneman, 1974 and Tversky, 2003, among many others): it is the tendency for individuals to feel happier and more comfortable when surrounded by people who share their beliefs, values, and opinions. This bias stems from the desire for social validation and the comfort of being in agreement with others, which reduces cognitive dissonance and enhances a sense of belonging.

3.3.2 Self-image

While they both care about the environment, E and G individuals differ from their self-image towards environmental issues. E individuals purchase the sustainable product, but also feel they do not do enough to help the environment. This sense of dismay is denoted by $\pi_g c_e > 0$ and thus increases with the share of G individuals in the population at a rate $c_e > 0$, as their largest number implies more news on the topic, more demonstrations in favour of the environment, and generally more exposition to environmental issues, with exacerbates the sense of inadequacy.

In contrast, G individuals, exert sufficiently high effort to help the environment, so that the do not feel any dismay. Their pro-environmental activity, however, is tiring and time consuming, so that they pay a utility cost of effort of $c_g > 0$. In what follows, we assume $c_e > c_g$: if all the population is composed of G individuals, then the dismal cost faced by E individuals is definitely higher than the cost of effort. This assumption ensures that the adoption of the G strategy may be truly feasible. With slight abuse of notation, we define the utility cost differential as $\Delta c = c_e - c_g$.

Our assumptions on self-image are consistent with those developed in the relevant literature, see Brekke et al. (2003), Nyborg (2011) Czajkowski et al. (2017), among others. In these frameworks, individuals optimally choose their effort as a continuous variable towards the environment based on the cost of their self-image. Our model simplifies the modelling of self-image to take into account the social interaction (see below): the cost of self-image is discrete ($\pi_g c_e$ or zero) and, in turn, environmental effort is discrete (zero or c_g). We thus associate different choice to different types.

B-type individuals are generally not worried about the environment, and thus they normally do not pay any psychological cost. However, if a B individual meets a G individual, she is sensitised to environmental issues and pays the psychological cost, identical to that suffered by E individuals, of $\pi_g c_e$.

3.4 Matching process and dynamics

We analyse the long-run population configurations through an evolutionary model of social dynamics: time is continuous and individuals are paired at every instant repeatedly. Table 1 describes the payoff at any t of an individual of each type (row) according to the type she is matched (column).

Table 1
Stage game. Row's payoffs

	B	E	G
B	$u_{bb} = a + s - p_d$	$u_{be} = a - p_d$	$u_{bg} = a - \pi_g c_e - p_d$
E	$u_{eb} = a - \pi_g c_e - p_c$	$u_{ee} = a + s - \pi_g c_e - p_c$	$u_{eg} = a + s - \pi_g c_e - p_c$
G	$u_{gb} = a - c_g - p_c$	$u_{ge} = a + s - c_g - p_c$	$u_{gg} = a + s - c_g - p_c$

The type of matching depends on whether the PEB adopted by G types is private or public. Private PEB does not affect the way individuals meet and implies random matching: the probability of meeting an individual of a certain type is given by the population distribution $(\pi_b(t), \pi_e(t), \pi_g(t))$. In contrast, public PEB forces all individual types to meet G individuals while they are publicly exerting their effort. We denote as $\beta \in [0, 1]$ the probability that the PEB is public.

Indicating a generic type $i \in \{b, e, g\}$, the expected payoff of type i is

$$u_i(t) = (1 - \beta)\left[\pi_b(t)u_{ib} + \pi_g(t)u_{ig} + \pi_e(t)u_{ie}\right] + \beta u_{ig}. \tag{1}$$

We focus on dynamics where types evolve over time satisfying payoff monotonicity (Weibull, 1995). In a payoff monotonic dynamic, the proportion of a type with a higher payoff always has a higher growth rate than a type with a lower payoff. We assume that n is sufficiently large that realised utilities are approximated by expected utilities. The replicator dynamic that represents the update process is:

$$\dot{\pi}_g = \pi_g(t)\left[u_g - \overline{u}(\pi_e(t), \pi_g(t))\right], \tag{2}$$

$$\dot{\pi}_e = \pi_e(t)\left[u_e - \overline{u}(\pi_e(t), \pi_g(t))\right], \tag{3}$$

where $\dot{\pi}_i = \frac{d\pi_i(t)}{dt}$, and

$$\overline{u}(\pi_e(t), \pi_g(t)) = \pi_b(t)u_b(t) + \pi_e(t)u_e(t) + \pi_g(t)u_g(t), \tag{4}$$

with $\pi_b(t) = 1 - \pi_e(t) - \pi_g(t)$.

3.5 Population configurations

This system admits at most seven population configurations in steady state which, for the sake of exposition, we define as follows:

Definition 1 (Population configurations) *The possible steady-state population configurations are*

- *"All B", according to which* $\pi_b = 1$ *and* $\pi_e = \pi_g = 0$*;*
- *"All E", according to which* $\pi_e = 1$ *and* $\pi_b = \pi_g = 0$*;*
- *"All G", according to which* $\pi_g = 1$ *and* $\pi_b = \pi_e = 0$*;*
- *"No B", according to which* $\pi_e + \pi_g = 1$ *and* $\pi_b = 0$*;*
- *"No E", according to which* $\pi_b + \pi_g = 1$ *and* $\pi_e = 0$*;*

- *"No G", according to which* $\pi_b + \pi_e = 1$ *and* $\pi_g = 0$*;*

- *"Mixed", according to which* $\pi_b, \pi_e, \pi_g \neq 0$.

A convenient graphical representation of the possible population configurations is the simplex in Fig. 1. Each vertex represents the homogeneous populations configurations *All B*, *All E* and *All G*. Then, Fig. 1 indicates examples of the other non homogeneous polulations: any point within the symplex represents a *Mixed* configuration, while any point in the side of the symples is a configuration where only on type is missing.

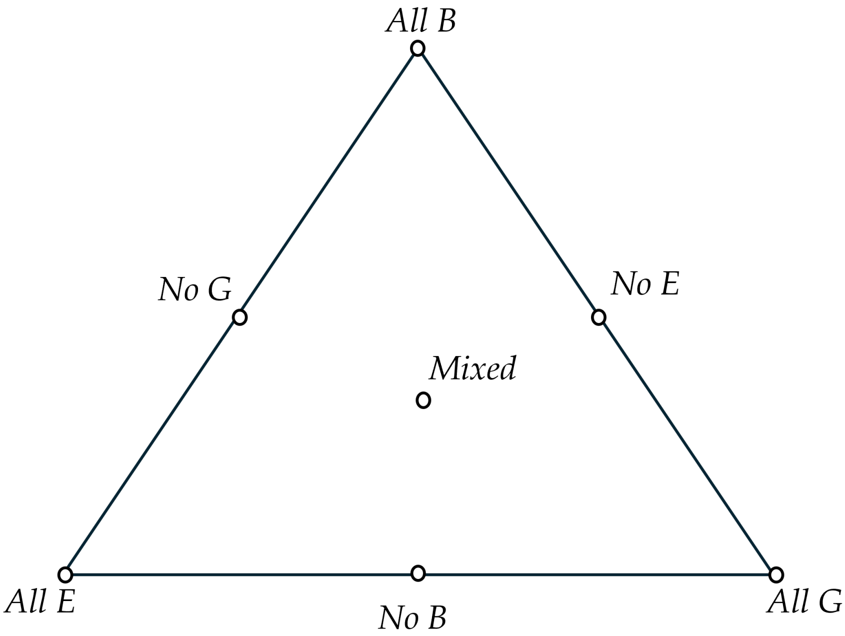

Figure 1. The distribution of types in a population.

4 Results

4.1 Existence and stability concept

We begin the presentation of our results by outlining the equilibrium existence, by introducing the conditions to focus on the relevant equilibria and by giving a definition of stability that we will employ throughout the analysis. First, to simplify the exposition, we define the following thresholds:

$$\overline{\beta} \equiv \frac{\Delta p + s + c_g}{2s}, \tag{5}$$

$$\widehat{\beta} \equiv \frac{\Delta p + s}{2s}, \tag{6}$$

$$\widetilde{\beta} \equiv \frac{(\Delta p + s)c_e + (\Delta c - 2s)c_g}{(\Delta c)(c_g + 2s)} \tag{7}$$

$$\underline{\beta} \equiv 1 - \frac{(s - \Delta p)c_e}{c_g \Delta c}. \tag{8}$$

The following proposition summarises the exitence conditions of each possible steady state population configuration.

Proposition 1 *The following steady-state population configurations exist:*

- *"All B", "All E", "All G" and "No B" for every β;*
- *"No E" if $\beta < \overline{\beta}$;*
- *"No G" if $\beta < \widehat{\beta}$;*
- *"Mixed" if $\beta \in \left(\min\left\{0, \underline{\beta}\right\}, \widetilde{\beta}\right)$.*

By comparing the equilibrium thresholds by Proposition 1, we are able to elicit further information about whether the equilibria are affected by social interactions.

Corollary 1 *For $\Delta p \geqslant s$, the type of social interaction represented by the level of β does not affect the steady-state population configuration.*

A possible explanation for Corollary 1 could be that a too high price of the clean product induces everyone to always choose the dirty product, irrespective of social interactions. Corollary 1 allows us focus our analysis on those equilibria where social interaction plays a role in determining the population configuration. Thus, in what follows, we assume

Assumption 1 *$\Delta p < s$.*

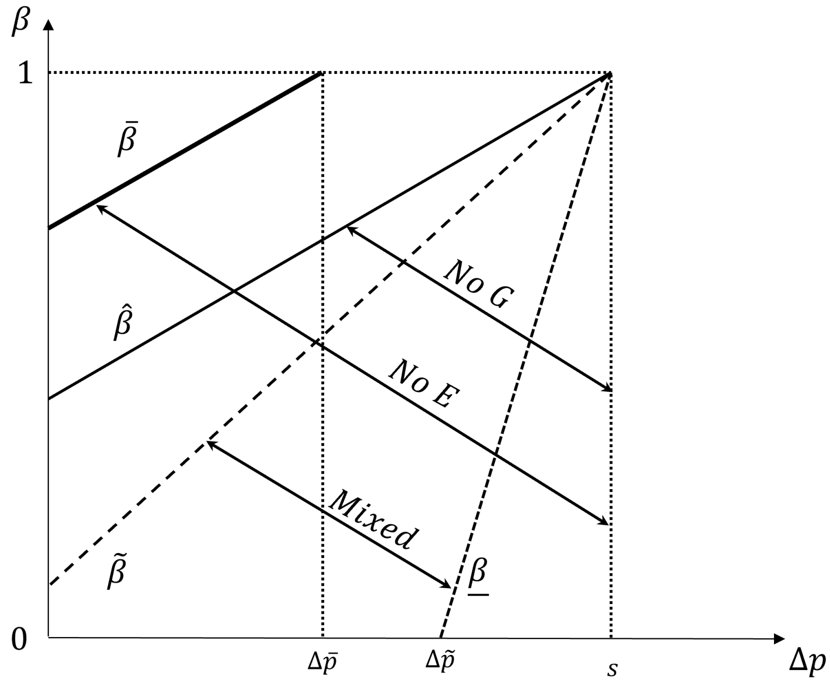

Figure 2. Existence of population configurations in equilibrium. *All B*, *All E*, *All G* and *No B* exist in the whole region considered.

Fig. 2 shows an example of the existence of equilibria that considers all thresholds of β in the interval $(0,1)$. In the figure, $\Delta\tilde{p}$ and $\Delta\underline{p}$ are defined in the the proof of Proposition 1 and ensure that $\overline{\beta} < 1$ and $\underline{\beta} > 0$, respectively. In addition, we also assumed

$$\Delta c > \frac{sc_g}{s + c_g},$$

allowing that $\tilde{\beta} > 0$ (see the proof in the Appendix for details).

The following definition will introduce the concept of stability that we will employ throughout the analysis.

Definition 2 (Stability, Hofbauer and Sigmund, 1998) *A steady-state population configuration is evolutionary stable if the trajectories starting close to it converge to it.*

Therefore, population configurations in the neighbourhood of a stable steady state are attracted to it.

In what follows, we consider first a situation in which PEB is only private. Then, we allow it to be public and see the effects on the composition of the population. The distinction between private and public PEB is commonly used in the literature (see, among others, Burn, 1991, Stern, 2000, Hunter et al., 2004, Thoyre, 2011, Hadler and Haller, 2011, 2013, Briscoe et al., 2019 and Yang and Wilson, 2023).

4.2 Beginning of history

We assume that, at the beginning of history, any form of PEB is completely absent. Many social contexts of the last century are similar to this situation. For example, in many Western countries after the Second World War, there was a strong emphasis on rebuilding the economy, creating jobs and improving living standards. During this period (the *post-war economic boom*), the focus was strictly on economic growth and technological progress, with little regard for the environmental consequences.

Another example is China during its period of rapid industrialisation from the 1980s to the early 2000s. During this period, China's primary focus was on economic development and poverty alleviation.

This is our starting point. In the absence of PEB, we automatically exclude the presence of G types. We can still expect that, a small share of individuals belong to E type: nevertheless, the economy tends towards a homogeneous population of B types, namely *All B*. From this initial configuration, we examine the emergence of private or public PEB.

4.3 Private PEB

Now suppose that, in the neighbourhood of *All B*, some individuals start exercising private PEB. The fact that an individual exerts PEB implies that she switches from type B or E to type G. In addition, since those who adopt forms of PEB do so *privately*, it implies $\beta = 0$. The following proposition shows the effects of introducing a private PEB over the population configuration in equilibrium.

Proposition 2 *If PEB is private, then the steady-state population configuration All B is evolutionary stable.*

Proposition 2 shows that the introduction of private PEB does not push the population configuration away from the neighbourhood of *All B* and thus does not affect the average consumption choice. In what follows, we examine whether interventions to promote sustainable consumption are effective in the presence of private PEB.

4.3.1 Interventions to support sustainable consumption

Here we consider the effects of the adoption of policies aimed at spurring the consumption of the clean good. In particular, we are interested in assessing the effectiveness of these interventions when PEBs are private.

A first intervention is the adoption of eco financial incentives to purchase the clean good. These are initiatives designed to encourage consumers to purchase environmentally friendly goods. For instance, some governments offer tax credits or rebates to consumers who purchase eco-friendly goods.[2] Also, retailers may provide cash-back offers or discounts on eco-friendly products like refrigerators, washing machines, or smart thermostats. [3]

In our model, the introduction of eco-incentives bring about a fall in the price differential, that is, the new price differential becomes $\Delta p' \in [0, \Delta p)$. Another possible intervention is the launch of environmental awareness campaings, to sensitise the population towards environmental issues. In our model, an increase in these kinds of activities may be modelled as an increase in the utility dismal cost $c_e' > c_e$ and, in turn, $\Delta c' > \Delta c$.

Finally, another possible intervention may come from local authorities that may be willing to support behavioural change towards the environment (Revell, 2013). Helping the adoption of PEB may involve advertising initiatives, coordinate groups of volunteers, or running campaigns to educate residents about reducing waste.[4] The support of PEB from local authorities may be modelled here as a reduction in the utility cost of effort to adopts PEBs, $c_g' < c_g$ and, in turn $\Delta c' > \Delta c$. Finally, the government may also consider to introduce a combination of these policies.

[2]In the United States, there are federal tax credits available for buying energy-efficient appliances, electric vehicles (EVs), or solar panels. The federal tax credit for purchasing an electric vehicle can be up to $7,500.

[3]For example, the UK's "Boiler Upgrade Scheme" provides a grant of up to £5,000 for homeowners who replace old boilers with more energy-efficient heating systems.

[4]For instance, the "Plastic Free July", supported by local councils around the world, is a campaign encouraging communities to reduce their plastic waste by choosing reusable alternatives.

The next corollary outlines the effects of such interventions.

Corollary 2 *Suppose the steady state is "All B" and PEB is private. Also, suppose that the government either (i) introduces eco-incentives, (ii) launches environmental awareness campaigns, (iii) support PEBs or (iv) adopt a combination of these policies. Then, "All B" is again an evolutionary stable steady state.*

Corollary 2 shows that the sole incentive to purchase clean product is not sufficient to spur a change in consumption habit. The same applies to the promotion of environmental awareness, as well as support of local authorities.

4.4 Public PEB

We now suppose, again starting close to *All B* population configuration, that at some point in the history some individuals engage in PEB, but now the pro-environmental behaviour is public. Again, an individual who exerts PEB basically becomes type G, but now it affects the nature of matching: now there is a positive probability $\beta > 0$ that the matching is not random: individuals are paired with probability β with someone who engages in PEB publicly.

Proposition 3 *If PEB is public and $\beta > \widehat{\beta}$, then "All B" is evolutionary unstable. "All E" or "All G" are the only evolutionary stable steady-state population configurations.*

Fig. 3 shows the possible stable equilibria when starting from initial conditions close to *All B*. Private PEB corresponds to the case in which $\beta = 0$ (thick line), from which the results of Corollary 2 are intuitive. Once PEB becomes public and some individuals change their type to E or G, the population configuration in equilibrium tends to *All B* again if public PEB is not too strong and if the price differential is very high (i.e., any combination of $(\Delta p, \beta)$ such that $\beta < \widehat{\beta}$). Otherwise, *All B* is not longer stable and may be eclipsed by either *All E* or *All G* configurations. Thus, the introduction of public PEB may induce the proliferation of green individuals of both types.

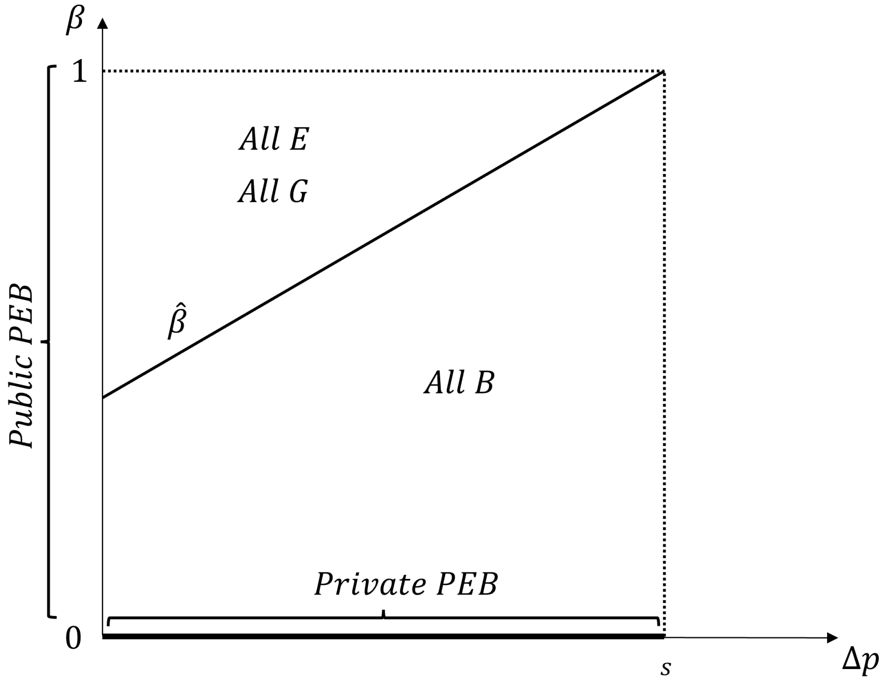

Figure 3. Stability of population configurations in equilibrium with initial conditions close to *All B*.

4.4.1 Interventions to support sustainable consumption

As in the case of private PEB, we again consider the effectiveness of the adoption of measures to promote sustainable consumption, in this case when PEB are public. Differentiating $\widehat{\beta}$ with respect to Δp, one gets

$$\frac{\partial \widehat{\beta}}{\partial \Delta p} = \frac{1}{2s} > 0,$$

from which we can state

Corollary 3 *Suppose the starting point is close to "All B" and PEBs is public. Then, the introduction of eco-incentives may increase the chance to switch to the basin of attraction of "All E" or "All G".*

The results in Corollary 3 stem from the comparative static analysis of the equilibrium population configurations with public PEB. In particular, the effects of introducing eco-incentives affect the configuration outlined in Proposition 3, and in particular the position of $\widehat{\beta}$. On the other hand, the support of PEBs by local authorities or the introduction of environmental awareness campaigns seem ineffective to take the population away from *All B*.

5 Robust population configurations

Up to this point, the dynamics of the model considered is deterministic, in the sense that, in the long run the types of individuals are determined by the initial conditions. Since there are more evolutionary stable population configurations, then the trajectories converge to the evolutionarily stable population configuration closest to the initial conditions. The underlying assumption is that individuals choose their type rationally. As a consequence, if the initial conditions are near to *All B* they would not converge to it only if $\beta > \widehat{\beta}$, since in this case the *All B* population configuration is not evolutionarily stable: they will turn into G or E types, depending on whether the initial condition is closer to *All G* or *All E*.

In this section, we extend the baseline analysis by considering the possibility that individuals choose a type through non-rational response behaviour. This can be interpreted as random events: behavioural innovations, exogenous shocks, experimentation, whim, error and intentional acts that wish to influence population outcomes but whose motivations are not considered in the analysis.

Allowing for idiosyncratic behaviour turns our dynamical system into an ergodic process, according to which the long-run steady state is independent on the initial conditions. In this new context, the population configuration will depend on the frequency of nonrational behaviour necessary to dislodge the population from the configuration in which it stands.

In particular, the relevant point here is to evaluate which population configuration requires more idiosyncratic behaviour to dislodge for a different configuration or, to put it differently, less idiosyncratic behaviour to adopt if the population is on a different configuration. The number of idiosyncratic behaviour necessary to transit from you population configuration to another is called *resistance* (Young, 1993). This is directly proportional to the size of the basin of attraction: the larger the basin of attraction of one population configuration (say A) compared to others', the less likely that trajectories starting close to that configuration converge to other configurations, and the more likely that trajectories starting to other configurations will converge to A.

Accordingly, a convenient concept to adopt is that of robust population configuration.

Definition 3 (Robustness, Bowles, 2003) *A steady-state population configuration is robust if it has the largest basin of attraction.*

Before outlining the results, we define the following thresholds:

$$\widehat{\beta}_r \equiv \frac{\Delta p}{s}, \tag{9}$$

$$\widetilde{\beta}_r \equiv \frac{4\Delta p - 1 + 4\gamma}{4s/c_e + 1}, \tag{10}$$

where $\gamma \equiv \frac{c_g}{c_e} \in (0,1)$ is the ratio between the effort cost of exerting PEB and the self-image cost. Subscript r stands for "robust". The next proposition outlines the conditions under which a convention is stochastically stable.

Proposition 4 *Suppose* $\beta < \min\left\{\widehat{\beta}_r, \widetilde{\beta}_r\right\}$. *Then All B is a robust population configuration. For* $\gamma < \frac{1}{2}$, *All G is a robust population configuration for* $\beta > \widetilde{\beta}_r$. *For* $\gamma > \frac{1}{2}$, *All E is a robust population configuration for* $\beta > \widehat{\beta}_r$.

Fig. 4 illustrates the result graphically, notice that the point in γ such that $\widehat{\beta}_r = \widetilde{\beta}_r$ amounts to

$$\widehat{\gamma} = \frac{\Delta p + s}{4s} < \frac{1}{2}.$$

In the range $(\widehat{\gamma}, \frac{1}{2}) \times (\widehat{\beta}_r, \widetilde{\beta}_r)$, labelled "Indet", it is not possible to determine which population configuration is robust. Consistent with the baseline analysis, the probability of public PEB must be sufficiently high to switch from *All B*. Furthermore, a relatively higher self-image cost compared to the utility cost of effort ($\gamma < \frac{1}{2}$) favours the emergence of *All G* and *vice versa*.

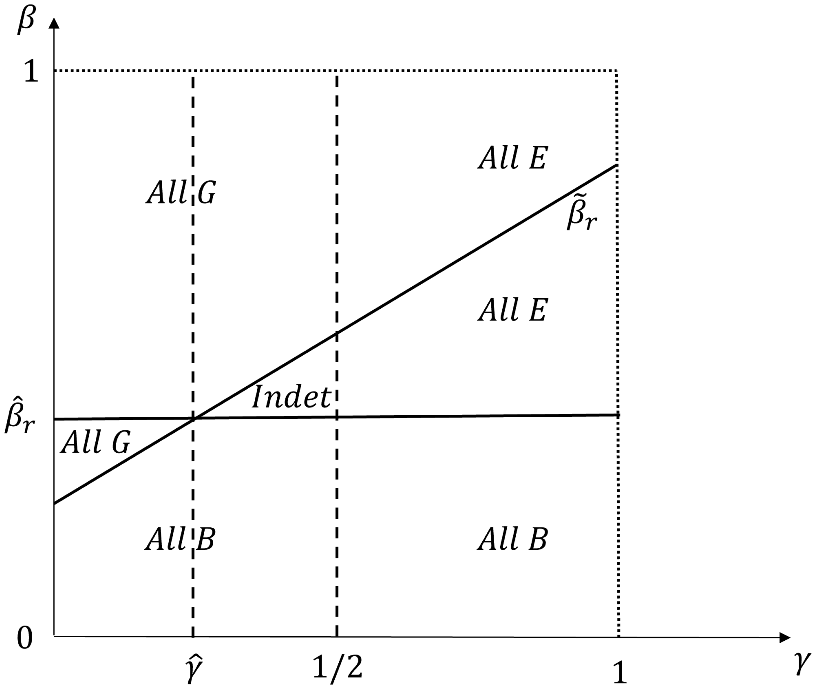

Figure 4. Idiosyncratic behaviour. In the area *Indet* (indeterminate) is not possible to establish which population configuration is robust.

6 Concluding remarks

In this paper, we have investigated the impact of public pro-environmental behaviour on sustainable consumption choices. We have argued that witnessing individuals actively working to improve the quality of the environment inspires others to emulate them. We used a social learning model in which individuals interacted in pairs and chose their roles based on different environmental attitudes and purchasing decisions.

In our framework, public PEB increased the likelihood that individuals would meet others who openly engaged in pro-environmental behavior, thus influencing their self-perception and concern for environmental issues. Then, we have assessed how public PEB interacted with pro-environmental policies. Our results suggest that public PEB encourages the population to adopt sustainable consumption practices and enhances the effectiveness of eco-incentives.

An interesting extension of the present analysis is the inclusion of “confirmation bias” in the social interaction analysis. Confirmation bias is a cognitive bias where individuals prefer to seek out, engage with and interpret information that is consistent with their existing beliefs or opinions (see, for instance, Sunstein, 2001). This bias also leads people to engage primarily with others who share similar views or backgrounds, reinforcing their existing perspectives and reducing exposure to differing viewpoints. As a result, confirmation bias can foster the formation of homogeneous social networks where dissenting opinions are less likely to be encountered or considered.

In our framework, confirmation bias can be modelled as *assortativity*, where individuals of a certain type have a certain probability of meeting others of the same type, thus weakening the probability of random matching. Unfortunately, the inclusion of confirmation bias in the framework with public pro-environmental behaviour would have prevented analytical results. Be that as it may, the inclusion of confirmation bias in the analysis of public pro-environmental behaviour is left for future research.

Appendix

Proof of Proposition 1

The population configurations *All B*, *All E* and *All G* always exist, since 0 and 1 are always solutions of the differential replicator differential equation.

Configuration *No B* exists because it amounts to $\underline{\pi}_g + \underline{\pi}_e = 1$, with

$$\underline{\pi}_g = \frac{c_g}{c_e}, \qquad \underline{\pi}_e = \frac{\Delta c}{c_e}.$$

Configuration *No G* is defined by

$$\hat{\pi}_e = \frac{\Delta p + (1-2\beta)s}{2(1-\beta)s}, \qquad \hat{\pi}_g = 0.$$

A close inspection shows that $\hat{\pi}_e > 0$ for

$$\beta < \hat{\beta} \equiv \frac{\Delta p + s}{2s},$$

while $\widehat{\pi}_e < 1$ for $\Delta p < s$.

Configuration *No E* is defined by

$$\overline{\pi}_g = \frac{-2(1-\beta)s - \beta c_e + \sqrt{(c_e+2s)^2\beta^2 - 4\beta(\Delta p c_e + 2c_e c_g + 2s^2) + 4(\Delta p c_e + c_e c_g + s c_e + s^2)}}{2(1-\beta)c_e},$$

$$\overline{\pi}_e = 0.$$

Notice that $\overline{\pi}_g = 0$ for $\beta \in \{\overline{\beta}, 1^-\}$, where

$$\overline{\beta} \equiv \frac{\Delta p + s + c_g}{2s},$$

and 1^- stands for a left neighborhood of 1 (remember that $\beta \in [0,1]$). Define $\overline{\pi}_g(\beta)$ as $\overline{\pi}_g : [0,1) \to (0,1)$. If $\overline{\pi}_g$ is a concave up parabola of β then $\overline{\pi}_g > 0$ for $\beta \in (0, \overline{\beta})$. While if $\overline{\pi}_g$ is a concave down parabola of β then $\overline{\pi}_g > 0$ for $\beta \in (\overline{\beta}, 1)$. Since $\lim_{\beta\to\pm\infty} \overline{\pi}_g = 1$, then $\lim_{\beta\to 1^-} \overline{\pi}_g = -\infty$, and $\overline{\pi}_g{}'(\beta) < 0$. This implies that, when $\beta = 1^-$, $\overline{\pi}_g = -\infty$ and, therefore, $\overline{\pi}_g$ cannot be a concave down parabola because the condition $\overline{\pi}_g > 0$ for every $\beta \in (0, \overline{\beta})$ is not satisfied. Therefore, $\overline{\pi}_g > 0$ for $\beta < \overline{\beta}$, while $\overline{\pi}_g < 1$ for $\Delta p < s + \Delta c$.

Configuration *Mixed* is defined by

$$\widetilde{\pi}_g = \frac{c_g}{c_e}, \qquad \widetilde{\pi}_e = \frac{c_e \Delta p + (1-2\beta)s c_e + (1-\beta)(\Delta c - 2s)c_g}{2(1-\beta)s c_e},$$

so that

$$\widetilde{\pi}_g + \widetilde{\pi}_e = \frac{c_e \Delta p + (1-2\beta)s c_e + (1-\beta)c_g \Delta c}{2(1-\beta)s c_e}.$$

Define $\widetilde{\pi}_g(\beta)$ as $\widetilde{\pi}_g : [0,1] \to (0,1)$ and $\widetilde{\pi}_e(\beta)$ as $\widetilde{\pi}_e : [0,1) \to (0,1)$. We get $\widetilde{\pi}_g + \widetilde{\pi}_e = 1$ for

$$\beta = \underline{\beta} \equiv 1 - \frac{(s - \Delta p)c_e}{c_g \Delta c}.$$

Since

$$\lim_{\beta\to\pm\infty} (\widetilde{\pi}_g + \widetilde{\pi}_e) = 1 + \frac{(c_g \Delta c)}{2s c_e} > 1,$$

then $\widetilde{\pi}_g + \widetilde{\pi}_e < 1$ only if $\widetilde{\pi}_g{}'(\beta) + \widetilde{\pi}_e{}'(\beta) < 0$. Thus we obtain

$$\widetilde{\pi}_g{}'(\beta) + \widetilde{\pi}_e{}'(\beta) = \frac{s - \Delta p}{2(1-\beta)^2 s},$$

which is negative for $\Delta p < s$. Moreover, we get that $\widetilde{\pi}_g + \widetilde{\pi}_e = 0$ for

$$\beta = \frac{(\Delta p + s)c_e + c_g \Delta c}{2sc_e + c_g \Delta c}.$$

Conversely, $\widetilde{\pi}_e = 0$ for

$$\beta = \widetilde{\beta} \equiv \frac{(\Delta p + s)c_e + (\Delta c - 2s)c_g}{(c_g + 2s)\Delta c}.$$

Since

$$\lim_{\beta \to \pm\infty} \widetilde{\pi}_e = \frac{(c_g + 2s)\Delta c}{2c_e s} > 1,$$

and

$$\widetilde{\pi}_e{}'(\beta) = \frac{(\Delta p - s)}{2s\,(1-\beta)^2} < 0,$$

for $s > \Delta p$, then $\widetilde{\pi}_e > 0$ and $\widetilde{\pi}_g + \widetilde{\pi}_e < 1$ for $\beta < \widetilde{\beta}$. Hence, the minimum between the β such that $\widetilde{\pi}_e = 0$ and $\widetilde{\pi}_g + \widetilde{\pi}_e = 0$. Notice that

$$\widetilde{\beta} - \underline{\beta} = \frac{(s - \Delta p)}{2s\,(1-\beta)^2} > 0,$$

for $s > \Delta p$. Hence, if $\Delta p > s$ the *Mixed* configuration does not exist. Conversely, if $\Delta p < s$ and $\beta \in (\min\{0, \underline{\beta}\}, \widetilde{\beta})$ then the *Mixed* configuration exists.

We now check the conditions such that the thresholds on β are within zero and one. First, $\widehat{\beta} > 0$, while $\widehat{\beta} < 1$ for $\Delta p < s$. Second, $\overline{\beta} > 0$ while $\overline{\beta} < 1$ for

$$\Delta p < s + \Delta c.$$

Then, $\underline{\beta} > 0$ for

$$\Delta p > \Delta \underline{p} \equiv s - \frac{c_g \Delta c}{c_e},$$

while $\underline{\beta} < 1$ for $\Delta p < s$. Finally, $\widetilde{\beta} > 0$ for

$$\Delta p > \frac{sc_g - \Delta c\,(c_g + s)}{c_e}.$$

Assuming

$$\Delta c > \frac{sc_g}{s + c_g},$$

ensures that $\widetilde{\beta} > 0$. □

Proof of Corollary 1

Notice that

$$\overline{\beta} - \widehat{\beta} = \frac{c_g}{2s} > 0,$$

and that

$$\frac{\partial \overline{\beta}}{\partial \Delta p} = \frac{\partial \overline{\beta}}{\partial \Delta p} = \frac{1}{2s} > 0, \tag{11}$$

$$\frac{\partial \widetilde{\beta}}{\partial \Delta p} = \frac{c_e}{\Delta c(2s + c_g)} > 0, \tag{12}$$

$$\frac{\partial \underline{\beta}}{\partial \Delta p} = \frac{c_e}{c_g \Delta c} > 0. \tag{13}$$

and finally that

$$\widehat{\beta}|_{\Delta p = s} = \widetilde{\beta}|_{\Delta p = s} = \underline{\beta}|_{\Delta p = s} = 1.$$

Hence, any population configuration obtained for $\Delta p \geqslant s$ is determined irrespective of the level of β. □

Proofs of Proposition 2 and Proposition 3

In what follows, we study the stability for every $\beta > 0$ in the plane (π_g, π_e), which corresponds to Proposition 3. The results of Proposition 2 are proven by setting $\beta = 0$.

The Jacobian matrix of the dynamical system (2)-(3) is given by

$$J = \begin{pmatrix} \frac{\partial \dot{\pi}_g}{\partial \pi_g} & \frac{\partial \dot{\pi}_g}{\partial \pi_e} \\ \\ \frac{\partial \dot{\pi}_e}{\partial \pi_g} & \frac{\partial \dot{\pi}_e}{\partial \pi_e} \end{pmatrix}$$

where

$$\frac{\partial \dot{\pi}_g}{\partial \pi_g} = [4c_e\pi_g^3 + (6s - 6c_e + 3\pi_e c_e)\pi_g^2 + (1-\pi_e)(2c_e - 8s)\pi_g + 2s\pi_e^2 - (4\pi_e - 2)s]\beta, \tag{14}$$

$$- 4c_e\pi_g^3 - (3c_e - 6s - 3\pi_e c_e)\pi_g^2 - (2\Delta p + 2c_g + 6s + 2\pi_e c_e - 8\pi_e s)\pi_g + c_g + s - 3\pi_e s + 2s\pi_e^2,$$

$$\frac{\partial \dot{\pi}_g}{\partial \pi_e} = \{[\pi_g^2 c_e + (4s - c_e)\pi_g - 4(1-\pi_e)s]\beta + c_e\pi_g^2 + (4s - c_e)\pi_g + \Delta p - 3s + 4\pi_e s\}\pi_g, \tag{15}$$

$$\frac{\partial \dot{\pi}_e}{\partial \pi_g} = \{[3c_e\pi_g^2 + (4s - 4c_e + 2\pi_e c_e)\pi_g + c_e - 4s - \pi_e c_e + 4\pi_e s]\beta + 3c_e\pi_g^2 + (4s - 2c_e + 2\pi_e c_e)\pi_g,$$

$$+ \Delta c - \Delta p - 3s - \pi_e c_e + 4\pi_e s\}\pi_e, \tag{16}$$

$$\frac{\partial \dot{\pi}_e}{\partial \pi_e} = \{c_e\pi_g^3 + [2s - 2(1-\pi_e)c_e]\pi_g^2 + (c_e - 4s - 2\pi_e c_e + 8\pi_e s)\pi_g + 6s\pi_e^2 - 8s\pi_e + 2s\}\beta, \tag{17}$$

$$- c_e\pi_g^3 - (c_e - 2\pi_g - 2\pi_e c_e)\pi_g^2 - (\Delta p - \Delta c + 3s + 2\pi_e c_e - 8\pi_e s)\pi_g - \Delta p + s - 2\pi_e\Delta p - 6\pi_e s + 6s\pi_e^2.$$

First, we verify the condition of stability of the equilibrium *All B*. By checking on the trace and determinant of $(\pi_g, \pi_e) = (0, 0)$, we obtain

$$\text{tr}(0,0) = 4s\beta - 2(\Delta p + s)c_g, \tag{18}$$

$$\det(0,0) = 4s^2\beta^2 - 2[2(\Delta p + s) + c_g]s\beta + (\Delta p + s)(\Delta p + s + c_g), \tag{19}$$

where $\text{tr}(0,0) > 0$ for

$$\beta > \beta_0 \equiv \frac{2(\Delta p + s) + c_g}{4s}, \tag{20}$$

while $\text{tr}(0,0) < 0$ for $\beta < \beta_0$, with $\hat{\beta} < \beta_0 < \overline{\beta}$. Moreover, $\det(0,0) > 0$ for $\beta < \hat{\beta}$ and $\beta > \overline{\beta}$, while $\det(0,0) < 0$ for $\beta \in (\hat{\beta}, \overline{\beta})$. We can conclude that the state *All B* is

- attractor for $\beta < \hat{\beta}$.
- a saddle point for $\beta \in (\hat{\beta}, \overline{\beta})$.

- a repellor for $\beta > \overline{\beta}$.

We turn now to *All E*. By checking on the trace and determinant of $(\pi_g, \pi_e) = (0, 1)$, we obtain

$$\text{tr}(0,1) = \Delta p - s < 0, \tag{21}$$

$$\det(0,1) = -(\Delta p - s)c_g > 0, \tag{22}$$

for $\Delta p < s$. Therefore the state *All E* is stable whenever Assumption 1 holds.

Next, we study the stability of *All G*. By checking on the trace and determinant of $(\pi_g, \pi_e) = (1, 0)$, we obtain

$$\text{tr}(1,0) = \Delta p - s - \Delta c, \tag{23}$$

$$\det(1,0) = -[\Delta p - s - \Delta c]\Delta c. \tag{24}$$

Thus $\text{tr}(1,0) < 0$ and $\det(1,0) > 0$ for $\Delta p < s + \Delta c$. Therefore the state *All G* is stable whenever Assumption 1 holds.

Finally, we focus on *No B*. By checking on the trace and determinant of $(\pi_g, \pi_e) = (\underline{\pi}_g, \underline{\pi}_e)$, by getting

$$\text{tr}(\underline{\pi}_g, \underline{\pi}_e) = (\Delta p - s)c_e + (1-\beta)c_g \Delta c, \tag{25}$$

$$\det(\underline{\pi}_g, \underline{\pi}_e) = \frac{1}{c_e^2}\left[(\Delta p - s)c_e + (1-\beta)c_g \Delta c\right], \tag{26}$$

from which we know that $\text{tr}(\underline{\pi}_g, \underline{\pi}_e) > 0$ for $\beta < \underline{\beta}$, while $\text{tr}(\underline{\pi}_g, \underline{\pi}_e) < 0$ for $\beta > \underline{\beta}$. Moreover, $\det(\underline{\pi}_g, \underline{\pi}_e) > 0$ for $\beta < \underline{\beta}$ while $\det(\underline{\pi}_g, \underline{\pi}_e) < 0$ for $\beta > \underline{\beta}$. Therefore configuration *No B* is

- a repellor for $\beta < \underline{\beta}$,
- a saddle point for $\beta > \underline{\beta}$.

Notice that for $\beta \geqslant \widehat{\beta}$ there are five possible population configurations, namely, *All B*, *All E*, *All G*, *No B* and *No E*. Following the analysis carried out in the proof, the only stable equilibria for $\beta \geqslant \widehat{\beta}$ are *All E* and *All G*. *All B* and *No B* are unstable and, by exclusion (Shone, 2002), configuration *No E* is a saddle. □

Proof of Corollary 2

If $\beta = 0$, then

$$\begin{aligned} \text{tr}(0,0) =& -2(\Delta p + s)c_g & (27) \\ \det(0,0) =& (\Delta p + s)(\Delta p + s + c_g). & (28) \end{aligned}$$

Therefore, the *All B* steady state is always stable, since $\text{tr}(0,0) < 0$ and $\det(0,0) > 0$, regardless of the value of the parameters Δp, s, c_g. □

Proof of Proposition 4

In the plane (π_g, π_e), the point $(0, \hat{\pi}_e)$ is the invasion barrier between strategies B and E, point $(\underline{\pi}_g, 0)$ is the invasion barrier between strategies B and G, and, finally, point $(\overline{\pi}_g, \overline{\pi}_e)$ is the invasion barrier between strategies G and E.

Therefore, following Bowles (2003), *All B* is a robust population configuration if $\hat{\pi}_e > \frac{1}{2}$ and $\overline{\pi}_g > \frac{1}{2}$, *All G* is a robust population configuration if $\overline{\pi}_g < \frac{1}{2}$ and $\underline{\pi}_g < \frac{1}{2}$, and *All E* is a robust population configuration if $\hat{\pi}_e < \frac{1}{2}$ and $\underline{\pi}_g > \frac{1}{2}$.

In particular, $\hat{\pi}_e > \frac{1}{2}$ for

$$\beta < \hat{\beta}_r \equiv \frac{\Delta p}{s}, \tag{29}$$

while $\overline{\pi}_g = \frac{1}{2}$ amounts to

$$(c_e + 4s)\beta^2 - 4(\delta p + s + c_g)\beta + (4\Delta p - c_e + 4c_g) = 0, \tag{30}$$

which is convex in β with roots

$$\beta_1 = \frac{4\Delta p - c_e + 4c_g}{4s + c_e}, \qquad \beta_2 = 1,$$

so that $\overline{\pi}_g < \frac{1}{2}$ in the range (β_1, β_2). Denoting $\gamma = \frac{c_g}{c_e}$, we may define

$$\beta_1 = \widetilde{\beta}_r \equiv \frac{4\Delta p - 1 + 4\gamma}{4s/c_e + 1},$$

where

$$\widetilde{\beta}_r - 1 = \frac{2\Delta p - 2s + c_e - 2c_e + 2c_g}{2\,(4s + c_e)} < 0,$$

for $\gamma < \frac{1}{2}$. Hence $\overline{\pi}_g < \frac{1}{2}$ for $\beta > \widetilde{\beta}_r$.

We can easily conclude that *All B* is a robust population configuration if $\beta < \min\left\{\widehat{\beta}_r,\ \widetilde{\beta}_r\right\}$. Remembering that for $\beta > \widehat{\beta}$, *All B* is unstable, one may verify that $\widehat{\beta}_r < \widehat{\beta}$ for every Δp. Finally, *All G* is a robust population configuration for $\underline{\pi}_g < \frac{1}{2}$ and for $\beta > \widetilde{\beta}_r$, while *All E* is a robust population configuration for $\underline{\pi}_g > \frac{1}{2}$ and for $\beta > \widehat{\beta}_r$. □

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