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Abstract

The paper proposes a new financial mechanism that could be implemented to protect the environment of a tourist region. For this purpose, we investigate the potential consequences of two financial activities, issued by the local government (G) of a region R, which work like contracts between G and, respectively, visitors of R and firms operating in R. According to these contracts, agents who decide to visit R (firms that decide to adopt an environmental friendly technology) have to buy an option that entitle them to get a partial or total reimbursement if environmental quality in R turns out to be sufficiently low (high), namely, below (above) a given predetermined threshold level.

Using a two-population evolutionary game model, we analyze the dynamics emerging from the model and prove that under such fund rising mechanism the virtuous equilibrium (in which all firms adopt the pollution-free technology and all agents choose to visit the region) is always locally attractive. Furthermore, we show that the attraction basin of the poverty trap equilibrium (in which no firm adopts the clean technology and no tourist comes the region) can be decreased by raising the reimbursement offered by the local government to the visitors. Finally, using numerical simulations, it can be shown that the dynamics of the model may give rise to another attractive stationary state in correspondence of the environmental quality threshold determined by the government, as well as to a limit cycle that oscillates around the threshold.

Keywords: environmental protection; financial instruments; technological innovation; evolutionary dynamics

1 Introduction

In the last few years financial assets are receiving increasing attention in the economic literature as a suitable policy instrument to achieve environmental

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targets in terms of pollution abatement.[1]

In this paper we propose an environmental protection mechanism managed by the local government of a tourist region that combines the potentially conflicting interests of the tourists (who care for the environmental quality that they expect to enjoy in the region) and those of the firms operating in the region (the activity of which may damage the environmental quality of the region).

In particular, we propose the adoption of a mechanism based on two financial activities, issued by the local government (G) of a tourist region *(R)*, which work like contracts between G and, respectively, visitors and firms operating in R - and can be regarded as (cash-or-nothing) *environmental call (EC)* and *environmental put (EP)* options. More specifically, the individuals' and firms' choices can be described as follows.

A tourist who wishes to go on holiday in the region R must purchase the environmental call option EC sold by G at a given price $\widetilde{p}$. This instrument imposes a cost on the tourist if the environmental quality Q is sufficiently high, that is, above a given predetermined threshold level $\overline{Q}$, but offers the visitor the possibility of a reimbursement in the case of low environmental quality (namely, when $Q < \overline{Q}$). One can immagine that environmental quality is measured by some independent authority (e.g. a monitoring institution or a pool of scientists and experts who collect environmental data in the region) and that the threshold level $\overline{Q}$ is determined by the local government so as to safely satisfy the carrying capacity of the ecosystem of the region. Consequently, the EC can be interpreted as a self-insurance device that allows the visitor to "buy protection" against environmental degradation. Thus, potential tourists have to choose between the following strategies:

(T_1) visit the region R (and consequently buy the EC)

(T_2) do not visit the region.

Similarly, each firm operating in the region R has to choose between subscribing or not the environmental put option (EP) issued by G that binds the firm to adopt a new environmental-friendly technology. This option implies an additional cost for the firm given by the difference between the cost of the new, non polluting technology (c_{NP}) and that of the old, polluting technology (c_P), but offers financial aid as a reward to the firm for its effort to reduce pollution.

Therefore, potentially polluting firms that operate in region R have to choose between the following strategies:

(F_1) adopting the new environmental-friendly technology (and subscribing the EP)

(F_2) keeping on using the old polluting technology.

Hence, if $Q \geq \overline{Q}$, the tourists (i.e. those agents who choose T_1) bear a cost but can enjoy high environmental quality in region R, while the firms choosing F_1 receive financial support for their investments aimed at protecting the environment. In this case, the costs born by G to finance the firms that subscribe the EP can be compensated by the revenues that G cashes in from

[1] See Di Vita (2009) for an analysis of the importance that well-developed financial markets can have for environmental protection.

selling the EC to the tourists. In this way, G can achieve the goal of improving the environmental quality at a relatively low cost. If, on the contrary, $Q < \overline{Q}$, the tourists (who choose T_1) receive a reimbursement for the low environmental quality experienced during the period spent in R, while G can decide whether or not to reimburse the few firms choosing F_1 to induce other firms to imitate them.

We will assume the value of Q to depend on the number of firms that subscribe the EP and thus adopt the environmental-friendly technology. The government G determines prices and reimbursements taking into account, among other things, the number of visitors and firms who purchase the financial activities as well as the cost of the environmental-friendly technological innovation.

The aim of the paper is to study the dynamics arising in this context from the interaction among economic agents (firms and tourists). For this purpose, we introduce and investigate a two-population evolutionary game, where the population of firms strategically interacts with that of tourists. The evolution of tourists' and firms' behavior is modelled using the so-called replicator dynamics (e.g., see Weibull 1995), according to which a given choice spreads among the population as long as its expected payoff is greater than the average payoff.

The environmental protection mechanism proposed in the paper is completely innovative with respect to the policy instruments used so far and has never been applied before. It joints the idea of the environmental bond (described in the next section) together with a "satisfied or reimbursed"-like mechanism in which the unsatisfied customer can ask for refund of the money spent for a given good or service. The latter mechanism has been applied to a large number of goods and services in the market (e.g. fitness products, cosmetic products, house cleaning goods etc...). Surprisingly enough, however, it has never been applied to environment-related goods.[2]

In order to analyze the potential effects in this context of the financial options described above the paper will proceed as follows. Section 2 reviews the related literature, Section 3 introduces the model, Section 4 provides the basic mathematical results. Finally, a few concluding remarks will follow in Section 5.

2 Related literature

This paper builds upon two separate strands of the environmental economics literature: the one on defensive expenditures and the other on environmental policy instruments. The former research line investigates the consumption choices that agents can do to self-protect from environmental degradation. The ongoing degradation of many environmental goods leads economic agents to

[2]The only partial exception concerns special naturalistic tours offered by some tour operators, such as whale watching in New Zealand where the company guarantees a 80% refund of the ticket if no whale is seen during the tour. This mechanism, however, is unrelated to the firms' economic activity, therefore is completely different from the one described here as it cannot induce any technological progress effect.

purchase private and costly consumption goods to satisfy the same needs that were formerly met by common access natural resources, namely, resources that were once freely available at no cost. The notion of defensive expenditures and their role in enhancing the Gross Domestic Product (GDP) is the object of an increasing literature that dates back to the seminal papers by Leipert (1987 and 1989), and that gained new momentum in the last decade when several contributions (e.g. see Antoci and Bartolini, 1999 and 2004) showed that defensive expenditures can not only increase GDP, but also give rise to a self-feeding growth process that may lead the economy to a Pareto-dominated equilibrium. This result emerges not only in evolutionary contexts in which agents have bounded rationality (Antoci et al., 2008; Antoci and Borghesi, 2010), but also in neoclassic frameworks with perfectly rational economic agents (Bartolini and Bonatti, 2002, 2003; Antoci et al., 2005, 2010).

Like in the literature on defensive expenditures, also in the present case agents self-protect from environmental degradation. However, the mechanism proposed in this paper differs from the one examined in the literature on defensive expenditures for three main aspects. First, differently from the case of defensive expenditures in which agents defend *ex-post* from environmental degradation, in the present case agents self-protect *ex-ante* from possible environmental degradation. In other words, under certain circumstances (specified below in the analysis of the model) this mechanism may prevent environmental degradation and the local government can actually influence such circumstances by properly modifying the reimbursement level. Second, while in the case of defensive expenditures the agents self-protect by purchasing private substitute *consumption goods*, here agents defend themselves by purchasing *financial options* that allow for reimbursement depending on the realization of a given (environmental quality-related) state of the world. Third, while the production and consumption of private substitution goods may sometimes generate further environmental degradation (cf. Antoci and Borghesi, 2010, for a few examples), the self-protection mechanism described here can improve environmental quality by raising financial resources that the local government can use to promote new, less polluting technologies.

The second strand of the literature that is closely related to this paper is the one on the best policy instruments that can be adopted to reduce environmental degradation. In particular, the protection mechanism analysed here shares some common features with two financial instruments that can be issued to achieve a given environmental target, namely, the environmental bonds (*EB*) and the tradable permits (*TP*).

As argued by Costanza and Perrings (1990), the *EB* is an incentive-based instrument of environmental risk control that can be conceived as a generalization of the deposit-refund systems that have been applied in different contexts characterized by environmental risk (cf. Bohm, 1981; Huppes, 1988). In particular, the *EB* consists of a deposit that any agent whose activity may be environmental damaging has to pay to the regulation authority and that can be (totally or partially) reimbursed provided the agent can prove that he/she avoided the expected environmental damage of his/her activity.

The idea of the *EB* - originally introduced by Perrings (1987 and 1989) and subsequently further developed by Horesh (2000, 2002a and 2002b)[3]- shares some common features with other policy instruments. In particular, the price-refund mechanism underlying the *EB* is often considered equivalent to the joint implementation of an environmental tax plus a subsidy. The *EB*, however, is generally perceived as politically more attractive than these two alternative environmental instruments taken separately. In an *EB* system, in fact, subsidies (refunds) are self-financed by taxes (deposits), therefore -differently from environmental subsidies- the *EB* does not imply any worsening of the public budget. Moreover, the prospective of a refund often makes the *EB* more acceptable to public opinion than the environmental taxes, since in the *EB* the punishment is proportional to the damage effectively produced and the refund is received only by the agents who can prove to deserve them.

The financial instruments proposed in this paper are similar to the deposit-refund mechanism underlying the *EB*. However, they also present some different and innovative features with respect to the *EB* that can improve the functioning of the system. In the *EB*, in fact, the regulatory authority has to face considerable monitoring costs to check whether the evidence brought forward by each *EB* holder is actually correct and thus decide about the possible reimbursement of the deposit. In the present case, instead, the local government has to monitor only the aggregate value of the selected environmental indicator through an independent authority. This may have a twofold advantage: on the one hand, it lowers the governmental monitoring costs, on the other hand, it prevents the *EB* holders from having to prove that they are eligible for the reimbursement.

The tradable permits, first introduced and analyzed by Crocker (1966), Dales (1968) and Montgomery (1972), are the other policy instrument that has some aspects in common with the financial options examined here. As is well known, in the case of the tradable permits the regulatory authority initially allocates permits among the polluters (users) of the natural resource on the basis of an ecological indicator (e.g. carrying capacity) of the ecosystem taken into account. Polluters (users) then trade permits among themselves on the secondary market, leading to a market price for the pollution (exploitation) of the natural resource, which signals the scarcity of the resource. Similarly to the *TP*, even in the present case the action of the regulatory authority is based upon the information on the threshold level of environmental degradation that is communicated, for instance, from a pool of experts or a monitoring institution. As in the case of *TP*, moreover, even this mechanism may generate an incentive to adopt a more environmental friendly technology. In the case of *TP* this can derive from the

[3]Horesh (2002a and 2002b) proposed the auctioning of an *EB* that can be redeemed at face value only if a given environmental target is reached by the agents. The target level is thus determined by the government, while its achievement is left to the market. The price of the bond will be determined by the market's evaluation of how likely it is to achieve the environmental target. It follows that those who hold the bonds will have a strong incentive to reach the objective as soon as possible since this increases the bonds' price and thus enables them to gain the difference between the face value at redemption and the auction price payed at the beginning. In the last years, some authors (e.g. Gerard and Wilson, 2009) have suggested possible applications of the *EB* to different contexts.

desire to avoid the cost of purchasing the permits, while in the present case it can be induced by the financial aid received by each virtuous firm that adopts a pollution-free technology if the environmental target is achieved. Such an aid contributes to abate the costs of the innovative technology thus increasing the incentive to invest in the environmental-friendly technology.[4]

The present paper extends and further develops the idea originally proposed in two contributions by Antoci et al. (2007 and 2009a). These studies focused exclusively within the tourists population, namely, on agents who had already decided to visit the region and had to choose whether to pay an entrance ticket or buy a financial option. Differently from those previous contributions, in this paper we extend the analysis to the whole population of potential tourists allowing for the individual preliminary choice between visiting and not visiting the region. We then examine how this "upstream" decision affects the dynamics that emerge from the model and how the resulting visitors' payoff modify in its turn the number of tourists that decide to come to the region.

The present paper, moreover, differs from other contributions in this research line also in another respect. While other studies (e.g. Antoci et al., 2009b) do not allow for any reimbursement to the virtuous firms in case of low environmental quality, in the present context the government may decide to reimburse the firms for their effort in adopting a clean technology even if for the region as a whole the environmental quality target is missed. This mechanism avoids that the first clean firms that adopt the new technology get "punished" for the dirty behaviors of all other firms and may induce the latter to imitate the virtuous behaviors of the former, thus reinforcing the governmental support to the diffusion of the new technology.

3 The model

Let us assume that there exist two populations: one of firms that operate in region R, and the other of potential visitors of R. At each period of time t potential visitors and firms play a one-shot population game (i.e. all agents play the game simultaneously). Each potential visitor has to decide ex-ante whether to buy the EC and visit the region R (strategy T_1) or not to visit the region (strategy T_2). Analogously, each firm has to decide ex-ante whether to buy the EP and adopt the new environmental-friendly technology (strategy F_1) or to continue to employ the old polluting technology (strategy F_2). Only the potential visitors (firms) who decide to visit region (that adopt the new technology) can buy the EC (EP). We assume that potential visitors know ex-ante the criterion (specified below) that is used by the local government G to fix the price of the call option and the reimbursement levels, therefore they also know in advance the maximum price that they might have to pay to visit the

[4] See Requate (2005) for a review of the literature on the incentives to the adoption of an innovative technology generated by alternative policy instruments, and Coria and Hennlock (2010) for a discussion of the necessary policy adjustments in response to such technological change.

region. Mutatis mutandis, the same applies to the firms. At the end of the time period t, G decides whether to reimburse visitors and firms who bought the EC and the EP, respectively, according to the environmental quality data in region R reported by an independent agency.

We assume the two populations to be constant over the time and normalise to 1 their size. Let us indicate with the variable $x(t)$ the share of firms choosing F_1 at time t, $0 \leq x(t) \leq 1$, and with the variable $y(t)$ the share of potential visitors adopting choice T_1 at time t, $0 \leq y(t) \leq 1$.

We assume that the price $\widetilde{p}(x, y)$ of the EC depends on the proportion of firms choosing F_1 and of individuals choosing T_1. We denote with $\widetilde{r}_V(x, y) = \alpha_1 \widetilde{p}(x, y)$ the reimbursement due by G to these visitors when $Q < \overline{Q}$, where α_1 is a parameter satisfying the condition $0 \leq \alpha_1 \leq 1$. Notice that $\alpha_1 = 1$ means that the amount $\widetilde{p}$ is totally reimbursed, whereas if $\alpha_1 = 0$ visitors are not reimbursed at all. The latter case, therefore, corresponds to the traditional entrance ticket with fixed price that visitors have to pay to access some cities or regions, while if $\alpha_1 > 0$ visitors have the chance to get a (partial or total) refunding of the ticket in case of low environmental quality. Then, the payoff of a visitor buying the call option is $\beta Q - \widetilde{p}$ if the environmental goal is attained ($Q \geq \overline{Q}$), whereas the payoff is $\beta Q - \widetilde{p} + \alpha_1 \widetilde{p} = \beta Q - \widetilde{p}(1 - \alpha_1)$ in case it is not ($Q < \overline{Q}$); β is a strictly positive parameter.

The quality index Q is assumed to depend positively on the proportion x of firms adopting the environment-friendly technology, in particular, for simplicity, we assume $Q := x$. The payoff of strategy T_1 is therefore given by:

$$P_{T_1}(x, y) = \beta x - \widetilde{p}(x, y) \quad \text{if } Q = x \geq \overline{Q}$$

$$P_{T_1}(x, y) = \beta x - (1 - \alpha_1)\widetilde{p}(x, y) \quad \text{if } Q = x < \overline{Q}$$

where $\overline{Q} \in (0, 1)$ is a parameter fixed by the local government G.

For the sake of simplicity, we assume that:

$$\widetilde{p}(x, y) = \gamma + \delta y + \varepsilon x \tag{1}$$

where γ, $\varepsilon > 0$, $\delta \gtreqless 0$ and $\gamma + \delta > 0$.[5]

As the sign of δ suggests, an increase in the number y of tourists has an a priori ambiguous effect on the price of the EC. On the one hand, a rise in y increases the demand of call options which induces G to increase their price ($\delta > 0$). On the other hand, an increase in y tends to augment the entries available to G. As a consequence, the local government may decide to lower the price of the EC to attract further tourists ($\delta < 0$). The sign of δ, therefore, depends on which one of these two opposite mechanisms will tend to prevail.[6]

[5] The latter condition ensures that the price of the call option $\widetilde{p}$ is always strictly positive for any possible value of x and y.

[6] Observe that the price of the call option has an upper bound equal to $\gamma + \delta + \varepsilon$ if $\delta > 0$ (when $x = y = 1$), and to $\gamma + \varepsilon$ if $\delta < 0$ (when $x = 1$, $y = 0$). By properly setting the values of γ, δ and ε so that the upper bound is relatively low, the local government can attract potential tourists and can use the revenues from the EC to reimburse the virtuous firms, thus

An increase in the number x of non-polluting firms, instead, has always a positive impact on the price of the EC. A rise in x, in fact, improves the environmental quality of the region. To finance the larger amount of potential reimbursements to the clean firms, therefore, the government tends to increase the price of the EC, so that the revenues obtained from the tourists through the call options can contribute to finance the firms that adopt the new technology.

Without loss of generality, we can normalise to zero the payoff of individuals choosing T_2 (i.e. who decide not to visit the region):[7]

$$P_{T_2}(x, y) = 0$$

Turning now to the firm's decision process, the profits of a firm subscribing the put option are given by:

$$P_{F_1} = R(y) - c_{NP} + \widetilde{r}_F(x, y) \text{ if } Q \geq \overline{Q} \text{ (i.e. } x \geq \overline{Q})$$

$$P_{F_1} = R(y) - c_{NP} + \alpha_2 \widetilde{r}_F(x, y) \text{ if } Q < \overline{Q} \text{ (i.e. if } x < \overline{Q})$$

where:

$R(y)$ are the firm's revenues, which are an increasing function of the number y of visitors (and are independent of the adopted technology that is assumed to affect only the production costs);

$c_{NP} > 0$ is a parameter representing the cost of the non-polluting technology plus the cost of the put option sold by G;[8]

$\widetilde{r}_F(x, y)$ is the financial aid received by a firm choosing F_1 in case $Q \geq \overline{Q}$;

α_2 is a non-negative parameter ($\alpha_2 \geq 0$). If $\alpha_2 = 0$ then the government refunds the non-polluting firms only if the environmental target is achieved. This policy, however, can be perceived as excessively punishing by the firms that could potentially invest in the new environmental technology (a sort of "first-mover disadvantage"), thus inducing them not to do so. To avoid this undesirable consequence, in the model we allow for α_2 to have also positive values, so that the government may decide to reimburse the few virtuous firms that decided to make the technological investment effort and are thus not responsible for missing the target. In particular, if $0 < \alpha_2 < 1$ the reimbursement is lower if the environmental target is not achieved than if it is achieved. If $\alpha_2 = 1$ the refund is independent of whether the target is actually reached. In this way the virtuous firms are fully insured against the risk of being the only ones to make

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supporting the diffusion of non-polluting technologies in the region.

[7]Notice that the normalisation $P_{T2} = 0$ adopted here is a simplifying assumption that allows to interpret P_{T_1} in relative terms, namely, as the difference between the payoffs associated with the alternative strategies T_1 and T_2. For the replicator dynamics assumed in the model, in fact, what matters is the difference between the payoffs associated with the two alternative strategies, not the payoff deriving from each strategy (see (2) below). The same results would obviously hold in the model if we let P_{T2} be different from zero and increased P_{T_1} by P_{T2} (i.e. $P_{T_1}(x, y) = \beta x - (1 - \alpha_1)\widetilde{p}(x, y) + P_{T2}$).

[8]To simplify the analysis and without any loss of generality, the cost of the EP can obviously be set equal to zero. This would avoid that some firms with stricter budget constraints may be discouraged from purchasing the EP due to possible liquidity problems.

the investment choice. Finally, if $\alpha_2 > 1$ the reimbursement is even higher in case the environmental target is not achieved since the government wants to reward the first firms that moved along the innovation path in order to induce also the others to imitate their behavior.

If, instead, the firm keeps on using the polluting technology (strategy F_2), its profits are given by:

$$P_{F_2}(x, y) = R(y) - c_P$$

where c_P is the cost of the traditional (polluting) technology and it is: $c_{NP} > c_P > 0$.

We assume:

$$\widetilde{r}_F(x, y) = \lambda + \mu y + \nu x$$

where λ, $\mu > 0$ and $\nu \gtreqless 0$ are parameters fixed by G.

Notice that an increase in the share x of non-polluting firms has an apriori ambiguous effect on the financial aid received by each of them ($\widetilde{r}_F(x, y)$). On the one hand, in fact, a wider diffusion of the clean technology improves the environmental quality of the region. This increases the likelihood that the threshold level $\overline{Q}$ will be overcome, thus reducing the financial resources that G has to devote to refund the tourists and increasing the resources that can be devoted to support the clean firms ($\nu > 0$). On the other hand, a higher value of x increases the number of firms that are eligible for the reimbursement and thus it lowers, *ceteris paribus*, the reimbursement at disposal to each of them ($\nu < 0$).

An increase in the number y of visitors has, instead, an unambiguously positive impact on the financial aid to the firms choosing strategy F_1 (i.e. $\mu > 0$) since G can use the higher revenues deriving from the EC to raise its financial support to the "clean" firms.

The process of adopting strategies is modelled by the so called *replicator dynamics* (see, e.g., Weibull, 1995), according to which the better performing strategies spread within the populations at the expense of the alternative strategies, that is:

$$\begin{aligned} \dot{x} &= x(1-x)(P_{F_1} - P_{F_2}) \\ \dot{y} &= y(1-y)(P_{T_1} - P_{T_2}) \end{aligned} \qquad (2)$$

We assume the parameters to satisfy the following conditions:

$$
\begin{array}{ll}
C_1) & 0 \leq \alpha_1 \leq 1, \; \alpha_2 \geq 0 \\
C_2) & c_{NP} > c_P > 0 \\
C_3) & \beta, \gamma, \varepsilon > 0; \; \delta \lesseqgtr 0; \; \gamma + \delta > 0 \\
C_4) & \lambda, \mu > 0; \; \nu \lesseqgtr 0 \\
C_5) & \lambda + \mu y + \nu > c_{NP} - c_P \;\; \forall \; y \in [0,1] \\
C_6) & \beta > \gamma + \delta y + \varepsilon \;\; \forall \; y \in [0,1]
\end{array}
\tag{3}
$$

We have already described conditions $C_1 - C_4$ before. As to conditions C_5 and C_6, they imply that, whatever the number of visitors y, if the share x of firms adopting the non-polluting technology is sufficiently high ($x \sim 1$), the strategy F_1 is more remunerative than F_2 and the strategy T_1 is more remunerative than T_2, respectively.

4 Analysis of the model

Dynamics (2) is defined in $[0,1]^2$, namely in the unit square:

$$S = \{(x, y) : 0 \leq x \leq 1, 0 \leq y \leq 1\}$$

and is discontinuous (if $\alpha_1 \neq 0$ and/or $\alpha_2 \neq 1$) along the vertical line $x = \overline{Q}$. In particular, for $Q < \overline{Q}$ (i.e. $x < \overline{Q}$), the dynamics (2) is given by:

$$
\begin{array}{rcl}
\dot{x} & = & x(1-x)F(x, y, \alpha_2) = x(1-x)\left[c_P - c_{NP} + \alpha_2(\lambda + \mu y + \nu x)\right] \\
\dot{y} & = & y(1-y)G(x, y, \alpha_1) = y(1-y)\left[\beta x - (1-\alpha_1)(\gamma + \delta y + \epsilon x)\right]
\end{array}
\tag{4}
$$

while for $Q > \overline{Q}$ (i.e. $x > \overline{Q}$) it is given by:

$$
\begin{array}{rcl}
\dot{x} & = & x(1-x)F(x, y, 1) = x(1-x)\left[c_P - c_{NP} + \lambda + \mu y + \nu x\right] \\
\dot{y} & = & y(1-y)G(x, y, 0) = y(1-y)\left[\beta x - (\gamma + \delta y + \epsilon x)\right]
\end{array}
\tag{5}
$$

All sides of the square S are invariant, namely, if the pair (x, y) initially lies on one side, then the whole correspondent trajectory also lies on that side.

Notice that the conditions C_5 and C_6 can be rewritten, respectively, as $F(1, y, 1) > 0$ and $G(1, y, 0) > 0$, $\forall y \in [0, 1]$. Furthermore, indicating by $y = f(x, \alpha_2)$ and $y = g(x, \alpha_1)$ the functions implicitly defined by the equations $F(x, y, \alpha_2) = 0$ and $G(x, y, \alpha_1) = 0$, it is easy to check that the conditions $C_1 - C_6$ imply that:

1) $\beta - \epsilon > 0$.

2) the slope of $y = f(x, \alpha_2)$ is positive (negative) if $\nu < 0$ (respectively, $\nu > 0$); furthermore $f(1, 1) < 0$.

3) If $\delta > 0$, then the slope of $y = g(x, \alpha_1)$ is positive and $g(0,0) < 0$, $g(1,0) > 1$; if $\delta < 0$, then the slope of $y = g(x, \alpha_1)$ is negative and $g(0,0) > 0$, $g(1,0) < 1$.

According to properties (1)-(3), the straigth line $G(x, y, 1) = 0$ always intersects the edges with $y = 0$ and $y = 1$ of the square S. Furthermore, when the straight line $F(x, y, 1) = 0$ has positive slope, then it lies outside $[0,1]^2$.

It is easy to chech the following proposition concerning the stationary states of the system (4)-(5).

Proposition 1 *The stationary states with $x \neq \overline{Q}$ of the system (4)-(5) are:*

1) The pure population states $(x, y) = (0,0)$, $(0,1)$, $(1,0)$, $(1,1)$, where only one strategy is played in each population.

2) The intersection points (when existing), with $0 < x < \overline{Q}$, between the edges $y = 0, 1$ and the straight line $F(x, y, \alpha_2) = 0$; the intersection points (when existing), with $1 > x > \overline{Q}$, between the edges $y = 0, 1$ and the straight line $F(x, y, 1) = 0$.

3) The intersection point (when existing), with $0 < x < \overline{Q}$ and $1 > y > 0$, between the straight lines $F(x, y, \alpha_2) = 0$ and $G(x, y, \alpha_1) = 0$; the intersection point (when existing), with $1 > x > \overline{Q}$ and $1 > y > 0$, between the straight lines $F(x, y, 1) = 0$ and $G(x, y, 0) = 0$.[9]

¿From the above proposition it follows that there can exist at most ten stationary states with $x \neq \overline{Q}$.[10] These multiple alternative equilibria show very different features. At some of them (the vertices of the square S, point 1 of the Proposition above) all agents make the same choice within each population (either all buy the option or none does so). At other equilibria (along the borders of S, point 2 of the Proposition) a unique strategy is unanimously chosen by all agents in one population, whereas heterogeneous choices emerge in the other population. Finally, at the inner equilibria (inside S, point 3 of the Proposition) both populations of firms and visitors present the coexistence of heterogeneous strategies (some agents buy the options, others not). The next Proposition identifies which ones among the multiple equilibria described above can be locally attractive and thus can be reached by the dynamics of the model.

The stability properties of each stationary state $(\overline{x}, \overline{y})$ with $\overline{x} \neq \overline{Q}$ can be analyzed by evaluating the associated Jacobian matrix:

$$J(\overline{x}, \overline{y}) = \begin{pmatrix} (1-2\overline{x})F(\overline{x}, \overline{y}, \alpha_2) + \overline{x}(1-\overline{x})F_x(\overline{x}, \overline{y}, \alpha_2) & \overline{x}(1-\overline{x})F_y(\overline{x}, \overline{y}, \alpha_2) \\ \overline{y}(1-\overline{y})G_x(\overline{x}, \overline{y}, \alpha_1) & (1-2\overline{y})G(\overline{x}, \overline{y}, \alpha_1) + \overline{y}(1-\overline{y})G_y(\overline{x}, \overline{y}, \alpha_1) \end{pmatrix} \tag{6}$$

It is easy to check that the following proposition holds.

Proposition 2 *According to the Jacobian matrix (6), we have that:*

1) The pure population stationary state $(\overline{x}, \overline{y}) = (1,1)$ is always a sink.

2) The pure population stationary state $(\overline{x}, \overline{y}) = (0,0)$ is a saddle point or a sink; in particular, it is a sink if $F(0,0,\alpha_2) = c_P - c_{NP} + \lambda\alpha_2 < 0$.

[9]Notice that $F(x, y, \alpha_2) = 0$ and $F(x, y, 1) = 0$ are parallel lines.

[10]See below for an analysis of the case $x = \overline{Q}$.

3) The remaining stationary states of the system (4)-(5) are saddle points or sources.

¿From the above proposition we have that at most two stationary states with $x \neq \overline{Q}$ can be locally attractive: $(1,1)$ and $(0,0)$. The former is a "virtuous" equilibrium since all firms adopt the clean technology and all visitors come to the region. The latter, on the contrary, is a "vicious" equilibrium: no firm adopts the new technology, causing the local environmental quality to be low and thus unable to attract any tourist. Notice that while the virtuous equilibrium is always locally attractive, the vicious equilibrium can be so only if a specific condition is met (see point 2 of the Proposition above). Such condition is more likely to be satisfied if α_2 is sufficiently low and will certainly be met if $\alpha_2 = 0$, namely, if no reimbursement is given to the clean firms in case the overall environmental target is missed despite their efforts. This implies that the local government should sufficiently raise the reimbursement to the clean firms in order to avoid that the vicious equilibrium may occur.

The following proposition concerns the welfare properties of the two attracting stationary states $(1,1)$ and $(0,0)$.

Proposition 3 *Under the assumptions* $C_1 - C_6$*,* $P_{T_1}(1,1) > P_{T_2}(0,0)$ *and* $P_{F_1}(1,1) > P_{F_2}(0,0)$ *always hold.*

Proof. Notice that the payoffs evaluated in $(1,1)$ and $(0,0)$ are, respectively:

$$\begin{aligned} P_{T_1}(1,1) &= \beta - (\gamma + \delta + \varepsilon) \\ P_{F_1}(1,1) &= R(1) - c_{NP} + (\lambda + \mu + \nu) \end{aligned}$$

and

$$\begin{aligned} P_{T_2}(0,0) &= 0 \\ P_{F_2}(0,0) &= R(0) - c_P \end{aligned}$$

Therefore, $P_{T_1}(1,1) > P_{T_2}(0,0)$ always holds under assumption C_6 while $P_{F_1}(1,1) > P_{F_2}(0,0)$ always holds under assumption C_5. ■

As the Proposition shows, the virtuous equilibrium $(1,1)$ Pareto-dominates the vicious equilibrium $(0,0)$, that is, the payoffs of firms and visitors turn out to be higher when all agents buy the options than when none does so. Stated differently, the purchase by all agents of the financial options proposed by the local government would make everyone better-off.

So far, we focused attention on the number and features of the equilibria in the case $x \neq \overline{Q}$. As we will see below, however, the system (4)-(5) may admit also other attracting stationary states (beyond $(1,1)$ and $(0,0)$) along the line $x = \overline{Q}$, which are not stationary states of the system (4) or of the system (5), but become stationary states under the composite system (4)-(5). Such states are characterized by the fact that the vector fields of systems (4) and (5) point in opposite directions in correspondence of them (see Utkin, 1974).

In the next section we show through numerical examples the existence and welfare properties of these other attractors that lie along the line $x = \overline{Q}$ in which all strategies coexist, as compared to the attractors $(1, 1)$ and $(0, 0)$ in which all agents choose the same strategy within each population.

4.1 Numerical simulations

We start by considering a numerical example with $\alpha_1 = 0$ (i.e. no reimbursment is given to tourists when $Q < \overline{Q}$) and $\alpha_2 = 1$ (i.e. the financial aid to innovative firms does not change when Q crosses the threshold value $\overline{Q}$). Figure 1.a shows the arrows diagram of system (4)-(5) in such context and Figure 1.b represents the corresponding phase diagram. Notice that a bi-stable dynamic regime occurs where only two locally attractive stazionary states coexist: $(1, 1)$ and $(0, 0)$; the former Pareto-dominates the latter. Their basins of attraction are separated by the stable manifold of the saddle in the interior of the square S.

Figures 2.a-2.b show the arrows and phase diagram that emerge from the model when $\alpha_1 = 0.3$ and $\alpha_2 = 1.2$. In such context, the stationary states $(1, 1)$ and $(0, 0)$ are still locally attractive but another locally attractive stationary state P arises which lies along the threshold line $x = \overline{Q}$. Their basins of attraction are separated by the stable manifolds of the two saddle points lying in the interior of the square S. The stationary state $(1, 1)$ Pareto-dominates P, but P Pareto-dominates $(0, 0)$. Consequently P is a second-best outcome generated by our financing mechanism of technological innovation.

Beyond the equilibria and trajectories described above, it is possible to show that a limit cycle may also arise in the model. In this regard, Figure 3 shows an example with $\alpha_1 = 0.45$ and $\alpha_2 = 0.96$ in which there exists a locally attracting limit cycle LC in the interior of S; in Figure 4 the basin of attraction of such cycle is represented. Notice that the threshold line $x = \overline{Q}$ crosses the interior of the cycle; in such context, therefore, the joint action of systems (4) and (5) gives rise to a cyclic behavior of the shares x and y. All the states belonging to the cycle Pareto-dominate the stationary state $(0, 0)$ but are Pareto-dominated by $(1, 1)$.

Finally, in the numerical example considered in Figure 5 we show how the basin of attraction of the Pareto-dominated stationary state $(0, 0)$ change varying the reimbursment share α_1. As the figure shows, such basin shrinks when α_1 increases, thus suggesting that by increasing the reimbursement to the visitors the government may reduce the probability that the system eventually converges to the worst equilibrium $(0, 0)$.

5 Concluding remarks

The present paper sets forth a new financial instrument that may promote the diffusion of an environmental-friendly technological innovation in a tourist region. The simple mechanism proposed here requires: (i) that the government establishes ex-ante (for instance, on the basis of the carrying capacity of the local ecosystem) the threshold level below which the regional environmental quality is regarded as unsatisfactory for the tourists and (ii) that an independent authority (e.g. a pool of scientists) measures the actual local environmental quality to determine whether it has been above or below the established threshold over the examined period. To fix ideas, the threshold level might be determined by the maximum amount of water pollutants discharged in the sea by the local firms that operate in a tourist region. If water pollutants are above the carrying capacity of the ecosystem (i.e. environmental quality is below the threshold) the public administration reimburses the tourists for the disutility they suffered from the low environmental quality experienced during their holiday in the region. Moreover, it may decide to reimburse the firms that use the clean technology to support their virtuous behavior and induce others to imitate them. If, on the contrary, the water pollutants discharged by the firms are sufficiently low (i.e. environmental quality is above the threshold), then the public administration does not have to reimburse the tourists but only the firms that adopted the new technology for their effort in reducing pollution.

As it emerges from the analysis, the system admits multiple equilibria. If the tourists pay a simple entrance ticket to the region (with no chance of reimbursement, i.e. $\alpha_1 = 0$) and the firms receive a constant subsidy for the new technology (independently of the environmental quality achieved in the region, i.e. $\alpha_2 = 1$), then only the extreme equilibria $(1, 1)$ and $(0, 0)$ in which all agents adopt the same strategy in each population are attractors, while all other possible equilibria are saddles or repellors. The system, therefore, will either converge to the first-best outcome $(1, 1)$ or to the Pareto-dominated poverty trap $(0, 0)$ depending on the initial share of tourists and firms that buy the options. In the former case, all firms adopt the new technology so that the environmental quality is very high and all potential tourists come to the region. In the latter case no firm shifts to the non-polluting technology and none is attracted to visit the region. In this case, the model can thus be interpreted as a simple coordination game between firms and tourists whose interaction is mediated by the local government: if the agents of the two populations coordinate their strategies and buy the options offered by the government they are all better-off, otherwise if none does so they are all worse-off.

If, on the contrary, the reimbursement mechanism to firms and tourists depends on the environmental quality observed in the region, then the trajectories can converge to further equilibria beyond the extreme fixed points $(1, 1)$ and $(0, 0)$. In particular, the system may admit also an inner attractor along the threshold $\bar{Q}$ or a limit cycle within the unit square along which the regional environmental quality keeps oscillating around $\bar{Q}$. This suggests that a more ambitious environmental target set by the local government may favor the diffusion of the innovation technology: the higher is the environmental threshold established by the local government, the higher the number of firms that adopt the new technology at the inner equilibrium.

As pointed out above, the system is characterized by a path dependent process in which the initial distribution of x and y affects the probability of the final outcome that may emerge from the dynamics of the model. The local government, however, can influence such an outcome and thus "direct" the economy along the desired trajectory by modifying the reimbursements to firms and visitors. In particular, by increasing the reimbursement to the tourists, the local government can minimize the attraction basin of the vicious equilibrium $(0, 0)$, thus reducing the probability of ending up in a poverty trap.

Further research will be needed in the future to deepen the analysis of the proposal set forth in this paper, its possible implications and the difficulties that may arise in its actual application. In particular, it would be interesting to investigate the case in which -when the environmental quality is low- the government not only fully reimburses the tourists for the costs of the call option, but it has to give them also an additional compensation for the disutility provoked them by the bad environmental quality. In this respect, one could also think of introducing multiple threshold levels (rather than just one as in this paper) to distinguish between: (i) the case with extremely low environmental quality (that is potentially health-damaging and requires therefore a compensation to the tourists); (ii) the case of extremely high environmental quality (in which the firms deserve a premium for their successful environmental performance and the target consequently achieved) and (iii) the intermediate case in which environmental quality is sufficiently high (low) in which only the costs of purchasing the put (call) options are refunded to the firms (tourists). Although at first sight the first two policies (compensation/premium to the agents beyond the full reimbursement of the options cost) might look rather expensive for the public administration, one could obviously take account of this problem by introducing a balanced-budget constraint that the public administration has to satisfy over time. Finally, in our opinion it seems desirable to investigate what happens if we allow for a secondary market of the financial assets proposed here so that -once the put (call) options have been initially allocated among the individuals of the two populations- firms (visitors) are allowed to exchange them among themselves as it happens in the market of tradable permits. This is likely to modify the price of the options and thus also the dynamics that may emerge from the model, providing new insights on the potential risks and benefits deriving from the application of this mechanism.

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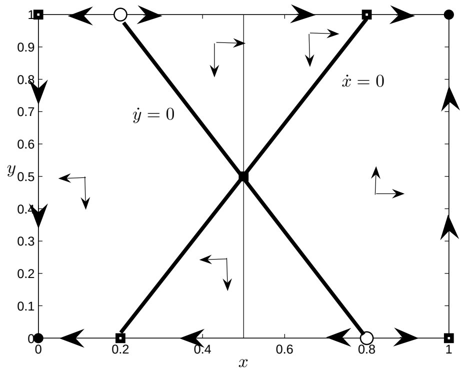
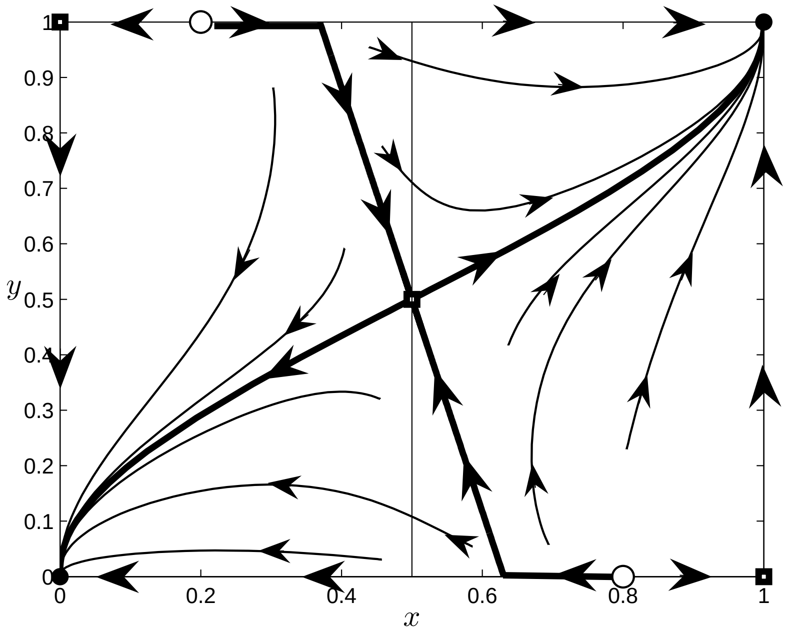
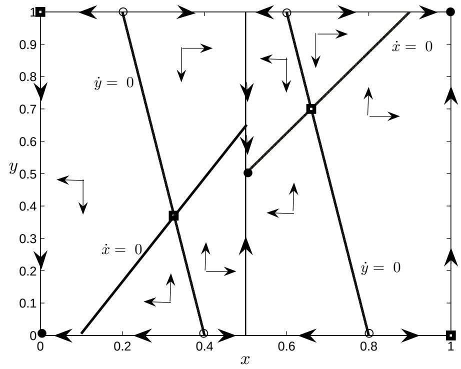


(a) isoclines $F(x, y, \alpha_2) = 0$ and $G(x, y, \alpha_1) = 0$

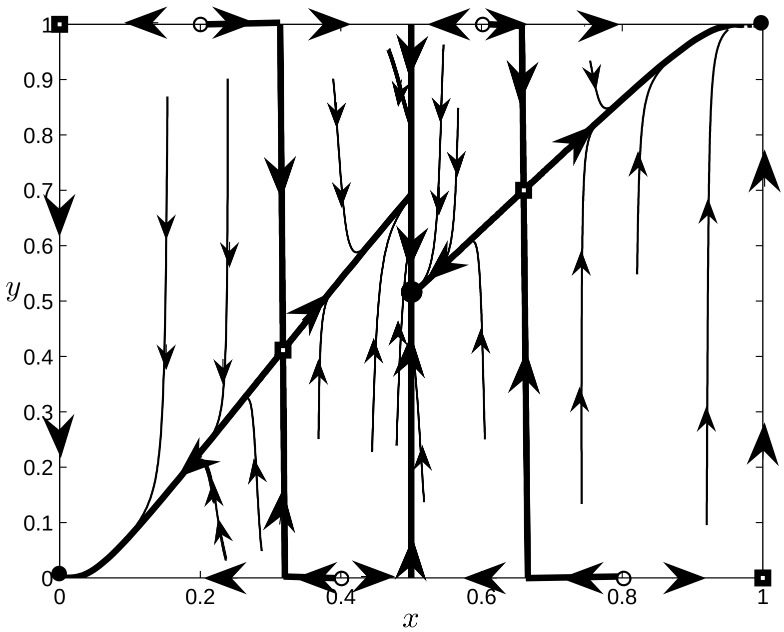


(b) trajectories and separatrix of the attraction basins

Figure 1: Black dots=attractors, white dots=repellors, square dots=saddles. Parameters value: $\alpha_1 = 0$, $\alpha_2 = 1$, $\beta = \frac{3}{2}$, $\gamma = \frac{1}{10}$, $\delta = \frac{3}{10}$, $\epsilon = 1$, $\lambda = \frac{7}{30}$, $\mu = \frac{2}{10}$, $\nu = \frac{1}{3}$, $C_P = \frac{1}{2}$, $C_{NP} = 1$, $\overline{Q} = 0.5$,



(a) arrows diagram



(b) phase diagram

Figure 2: Inner attractor along the threshold. Parameters value: $\alpha_1 = 0.3$, $\alpha_2 = \dfrac{12}{10}$, $\beta = 3.5$, $\gamma = .25$,$\delta = 2$ $\epsilon = 1$, $\lambda = \dfrac{2}{15}$, $\mu = \dfrac{1}{60}$, $\nu = \dfrac{1}{12}$, $C_P = 1$, $C_{NP} = 12/10$, $\overline{Q} = 0.5$

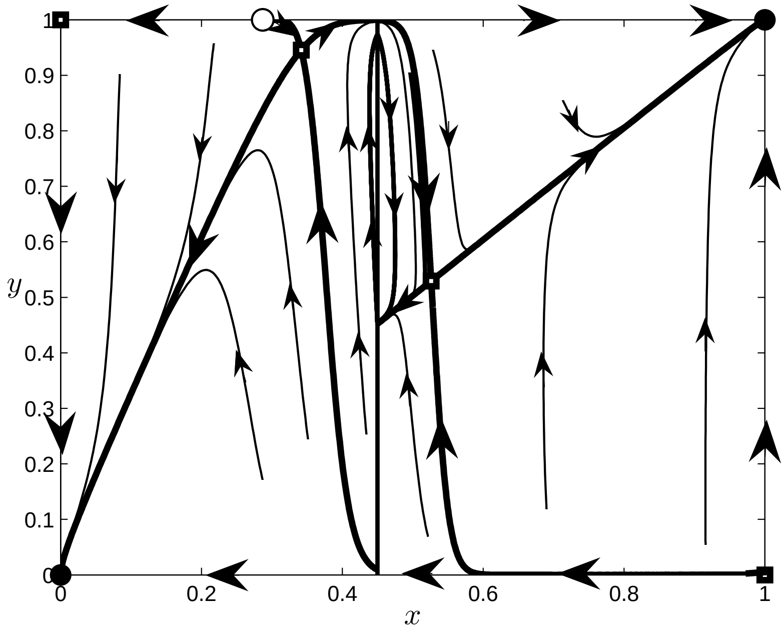


Figure 3: Limit cycle around the threshold. Parameters value: $\alpha_1 = \dfrac{45}{100}$, $\alpha_2 = \dfrac{96}{100}$, $\beta = 4$, $\gamma = \dfrac{1}{10}$, $\delta = \dfrac{9}{5}$, $\epsilon = 2$, $\lambda = \dfrac{81}{200}$, $\mu = \dfrac{1}{10}$, $\nu = \dfrac{9}{100}$, $C_{NP} = 1$, $C_P = \dfrac{1}{2}$, $\overline{Q} = 0.45$

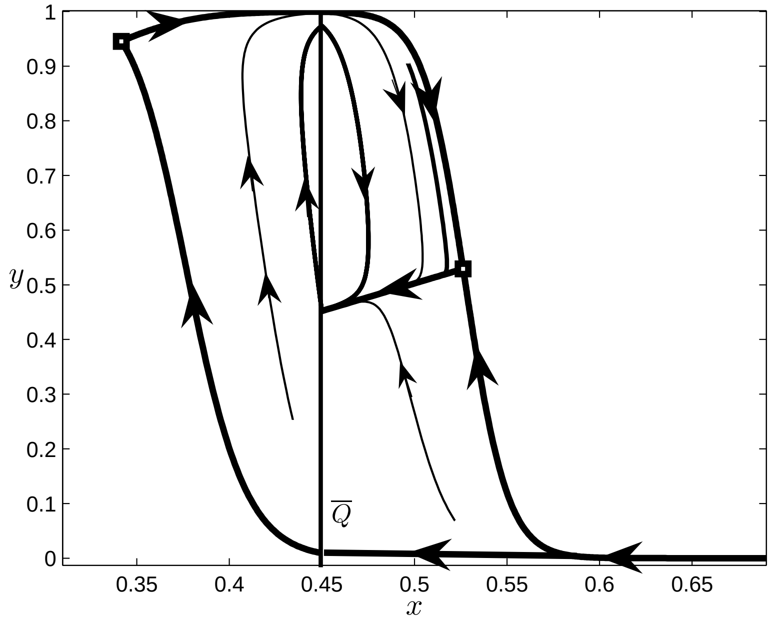
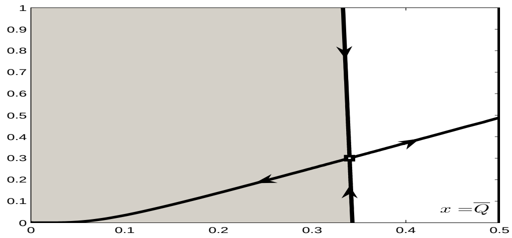
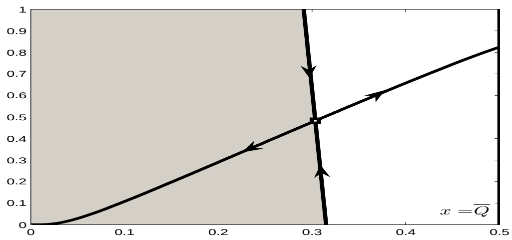


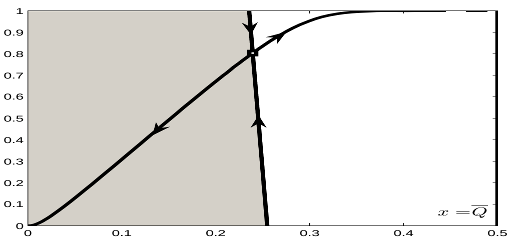
Figure 4: Attraction basin of the limit cycle



(a) $\alpha_1 = 0$



(b) $\alpha_1 = 0.3$



(c) $\alpha_1 = 0.6$

Figure 5: Changes in the attraction basin of $(0, 0)$ (shadow area) as α_1 increases. Same parameter values as in Figure 2.