A dynamic approach to voluntary environmental contributions

Unilateral commitments and ecolabels in tourism

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Working paper. Please do not cite

1. Introduction

Voluntary approaches are increasingly considered as relevant policy instruments to complement traditional command-and-control regulation (Anton, Deltas, & Khanna, 2004; Brau & Carraro, 2004; Dawson & Segerson, 2008; Delmas & Keller, 2005; Glachant, 2007; Khanna, 2001; Lyon & Maxwell, 2002; Sasidharan, Sirakaya, & Kerstetter, 2002; Segerson & Miceli, 1998). Voluntary environmental initiatives are defended as institutional changes in corporate culture towards self-regulation which incorporate environmental concerns in production decisions (Anton et al., 2004). Non-mandatory approaches to environmental protection include a diverse set of efforts that can be classified into three broad categories according to the degree of involvement of regulators or other third parties: unilateral commitments, negotiated agreements, and certified voluntary programs[1] (Delmas et al., 2005; Khanna, 2001). All these are considered voluntary initiatives since they have two basic characteristics: promoters of the initiatives are not obliged by law to launch the scheme, and target groups are not obliged to apply or join (WTO, 2002).

Given their non-mandatory nature, the economics literature generally holds the view that voluntary programs must generate short-term economic gains to promote

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1 Some examples are respectively, participation codes of environmental management (such as the Responsible Care program of the American Chemical Council), agreements between regulators and individual firms on environmental targets (such as the Project XL in the United States or the agreements under the Dutch National Environmental Policy Plan), and adoption of international certification standards for environmental management (such as the ISO 14001) (Anton et al., 2004; Dawson et al., 2008).

compliance[2] (Alberini et al., 2002; Dawson et al., 2008; Khanna, 2001). Consequently, it is suggested that voluntary programs connect private benefits to voluntary environmental action (Delmas et al., 2005). According to the literature, some motives behind a firm's decision to adopt a voluntary agreement are regulatory gains, demand effects, cost efficiency, and technical assistance (Amacher, Koskela, & Ollikainen, 2004; Anton et al., 2004; Arora & Gangopadhyay, 1995; Brau et al., 2004; Khanna, 2001; Lyon et al., 2002; Lyon & Maxwell, 2008; Portney, 2008; Vidovic & Khanna, 2007; Vidreras & Alberini, 2000).

Regulatory gains and demand effects have been the center of research attention in the past. The former suggests that firms may strategically adhere to a voluntary program to postpone or avoid the regulatory behavior of public agencies (Dawson et al., 2008; Glachant, 2007; Manzini & Mariotti, 2003; Segerson et al., 1998). The latter analyzes the market implications of product differentiation when consumers are concerned about environmental aspects of goods and services (Amacher et al., 2004; Arora et al., 1995; Conrad, 2005; Ibanez & Grolleau, 2008; Moraga-González & Padrón-Fumero, 2002; Sedjo & Swallow, 2002).

In this paper, we build on some of the theoretical foundations of the latter to develop a model of voluntary environmental initiatives by tourism users of a natural common-pool resource (CPR), which are an increasingly relevant reality, according to empirical studies (Ayuso, 2006, 2007; Buckley, 2002; Font, 2002; Mihalic, 2000; Sasidharan et al., 2002; UNEP, 1998; WTO, 2002). Our primary interest is to model the changes in incentives to undertake environmental contributions by CPR-using tourism firms when an ecolabel is introduced, that is, when an institutional change based on the voluntary adherence of firms is implemented. Tourism-related uses of natural resources are an increasingly relevant type of use of natural common-pool resources. Time-series empirical evidence has shown that traditional recreational uses, such as visits to national parks, hunting and fishing, camping, backpacking and hiking have been declining in the US and Japan over the last 20 years (Pergams & Zaradic, 2008). On the other hand, nature-based tourism has turned out to be the fastest growing segment of the global tourism market (Huybers & Bennett, 2003; Sirakaya et al., 1997)[3]. Despite this relevancy, limited efforts have been made to bring attention to the benefits that could be gained by a broader and deeper voluntary commitment to the environment by service organizations (Davis, 1991; Foster, Sampson, & Dunn, 2000; Grove, Fisk, Pickett, & Kangun, 1996). Given that the objective of voluntary initiatives is to complement

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[2] Alberini et al. (2002) lists personal satisfaction or utility gained from undertaking activities that protect the environment as one of the incentives to participate in voluntary programs. Because of interest in economic motivation of greener behavior, we do not consider this motivation even though some empirical evidence exists in tourism supporting that personal morality have a positive relationship with compliance with environmental codes of conduct by eco-tour operators (Sirakaya, 1997; Sirakaya & Uysal, 1997).

[3] International tourism accounts for US$856 billion tourism receipts and 903 millions of tourism arrivals (WTO, 2008).

regulatory frameworks (WTO, 2002), voluntary initiatives have to improve performance above legal compliance to achieve relevant improvements in the main problems of tourism (Buckley, 2002). This is particularly relevant since tourism is not very regulated by public authorities compared to other sectors (Ayuso, 2007)[4].

We consider two different voluntary environmental initiatives in tourism: unilateral commitments and ecolabels. We first consider a model where the only available environmental strategy to the population of firms is to undertake unilateral commitments. Later, we introduce an ecolabel as a second available environmentally-friendly strategy. We analyze the change in the environmental behavior of firms after the ecolabel has been created and identify the circumstances under which the certification program can be stable in the long run. Both models are presented for exogenous and endogenous levels of natural capital. By integrating the dynamics of the resource stock, as suggested by Sethi and Somanathan (1996), the stability of population configurations is considered together with the sustainability of resource use.

To do so, we adopt evolutionary game theory to build our model. Since evolutionary game theory studies *populations* playing games, rather than the behavior of rational *individuals*, it is particularly useful for studying institutional change (Friedman, 1991, 1998; Mailath, 1998). The origins of such an approach are in evolutionary biology, but the approach is increasingly being used in economic and social sciences (Nowak & Sigmund, 2004). Under evolutionary game theory, payoffs depend on players' actions and the actions of the co-players in the population. Strategies with high payoffs spread through learning, imitation, or other forms of cultural evolution (Friedman, 1991, 1998; Hofbauer & Sigmund, 2003). This shift in strategy has some inertia, which can be attributed to adjustment costs, information imperfections, or bounded rationality (Friedman, 1998). Furthermore, players do not systematically attempt to influence future play of others (Friedman, 1998), nor do they take into consideration the possibility that others adjust their behavior strategically (Mailath, 1998). One justification for this is the existence of a large number of players (Friedman, 1998; Mailath, 1998). This naïve behavior is one crucial difference between evolutionary games and repeated games in orthodox game theory (Friedman, 1998). A second major difference is that the focus of study of evolutionary game theory is the dynamic behavior of the system (Mailath, 1998), extending classical game theory away from the static doctrine of the Nash solution concept (Friedman, 1991; Hofbauer et al., 2003; Nowak et al., 2004)

The main advantage of using evolutionary game theory is that it enables the researcher to discriminate between different equilibria (Mailath, 1998; Nowak et al., 2004; Sethi et al., 1996). It is possible to distinguish stable from unstable equilibria and to identify the regions of initial conditions that eventually lead to a given

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[4] For example, it is reported that coastal regions are subject to impacts from tourism due to an inadequate legislative setting, administrative infrastructures, and managerial capabilities (Sasidharan et al., 2002).

equilibrium (i.e., basins of attraction) (Friedman, 1991, 1998). In addition, it is preferable in our analysis since it better considers the role of resources dynamics on the long run behavior of players. It is argued that standard game theory frequently fails to consider the dynamic nature of natural resources on equilibrium outcomes (Osés & Viladrich, 2007). This is partly because defining and interpreting subgame perfect equilibrium is easier with a discrete time approach, whereas analyzing a renewable resource model is more amenable to a continuous time approach (Tarui, Mason, Polansky, & Ellis, 2008). Finally, in evolutionary game theory, the equilibrium that players eventually reach is determined by the original distribution of players in the population, the underlying game, and the way strategies spread (Friedman, 1998; Hofbauer et al., 2003), i.e., history matters in achieving a steady state of the system (Mailath, 1998).

Evolutionary game theory has been previously applied to analyze voluntary environmental behavior (Osés et al., 2007; Sethi et al., 1996). Sethi and Somanathan (1996) analyze players' environmental behaviors in a population where players can extract low or high levels of a natural resource and where costly informal punishment (for those inflicting and suffering it) is possible among players in response to the observed behavior of others. Using the same methodology, Osés and Viladrich (2007) concentrate on results when environmentally sensitive players enjoy informal social benefits associated with responsible behavior. Unlike these previous studies, only market forces motivate voluntary environmental contributions in our model, and we consider two environmentally-friendly strategies as opposed to the non-green strategy. The incentives to participate in a voluntary environmental initiative depend on the comparison between profits resulting from unilateral commitments, ecolabels, and non-green alternatives.

The rest of the chapter is organized as follows. Section 2 presents some stylized facts for unilateral commitments and ecolabels in tourism. Sections 3 and 4 develop the models for unilateral commitments and ecolabels, respectively. In both cases, we first present the population dynamics, then the natural CPR dynamics, and finally the dynamics of the combined system. Results of sections 3 and 4 show that heterogeneous population compositions where one of the voluntary initiatives coexists with dirtier firms can be asymptotically locally stable, as homogeneous populations can be. Section 4 further shows that heterogeneous populations where unilateral commitments, ecolabels and dirty firms coexist can exist but cannot be stable. Section 5 presents the conclusion of the study.

2. Unilateral commitments and ecolabels in tourism

We are focusing on voluntary improvements of firms' environmental behavior as a result of unilateral commitments and ecolabels. We define unilateral commitments as those initiatives individually undertaken by firms that are not subject to external assessment of participants' behavior. This can include the internal development of firms' own environmental policies, adherence to codes of good practices, and other uncertified environmental practices. Some well known international unilateral commitments are the International Hotels Environment Initiative and the Tour Operators Initiative for Sustainable Tourism (WTO, 2002). Ecolabels, by contrast, imply the certification of a particular level of environmental performance in the production of a tradable product or service (Buckley, 1992), requiring the assessment of participants (Font, 2002). Some international examples in tourism are the Blue Flag Campaign and the Green Globe (WTO, 2002).

To model the environmental decisions of tourism firms regarding adherence to any of these voluntary initiatives, we build on some of the theoretical foundations of the literature on demand effects as motivators of voluntary action. We assume that consumers' individual decisions are based on utility-maximizing behavior and that part of the society includes in these decisions a trade-off between the environmental attributes of the good and other desired characteristics (Conrad, 2005). We further assume that consumer preference to purchase from green firms is well established and often revealed through increased willingness to pay for products viewed as "clean" (Amacher et al., 2004). Empirical evidence supports this assumption in tourism, especially in nature-based destinations[5]. Most conservative estimates show that up to 5 percent of the overall travel market would pay a premium for sustainable packages (Dodds & Joppe, 2005), and some regional results show that up to 52 percent of visitors would be prepared to pay an extra 10 percent for environmentally-friendly tourism products (PATA, 2007). In North Tropical Queensland, the lower boundary estimate for the willingness to pay by origin markets for an increase in the environmental quality from somewhat spoiled to unspoiled is more than US $480 for a fortnight's holiday (Huybers et al., 2003).

We separately consider three price premiums which might result from this demand effect[6]: a premium from green differentiation, a reputation premium, and a premium from increased environmental quality of the common-pool resource.

First, we hold that firms that preserve the natural environmental beyond the level that is legally mandated, i.e., firms which undertake unilateral commitments and firms which join ecolabels, can obtain a premium from green differentiation (as supported by empirical evidence in Álvarez, Burgos, & Céspedes, 2001; Carmona-Moreno, Céspedes-Lorente, & de Burgos-Jimenez, 2004; Claver-Cortés, Molina-Azoín, Pereira-Moliner, & López-Gamero, 2007; Kassinis & Soteriou, 2003). That is to say, firms can stand out among their competitors by following environmentally sensitive strategies to fill a green market niche (Alberini et al., 2002). Environmental attributes of tourism services are partially observable by

[5] By nature-based tourism we consider that type of tourism which is reliant on the natural environment as the principal component of the product or an essential setting for the operation activity (Buckley, 2002).

[6] See Sedjo and Swallow (2002) for a discussion on the circumstances under which a willingness to pay for environmental attributes of goods by a significant proportion of consumers results in price differentials for environmentally-friendly firms.

consumers (are not pure credence attributes), since there is a high interaction between production and consumption, which can have environmental management implications[7] (Ayuso, 2006; Stoeckl, 2004). Marketing has been effective at taking advantage of this differentiation premium and moving the demand towards environmentally friendly firms (WTO, 2002).

Second, tourism firms which belong to an ecolabel can obtain a reputation premium from their environmental efforts (as defended by Buckley, 2002; Font, 2002; WTO, 2002). The high level of tourist response to ecolabeled products has been upheld as one of the most telling indicators of the strength of environmental concern among the general public in many developed nations (Buckley, 2002). Empirical findings show that, among hotels, being enrolled in certification programs with higher levels of environmental performance is significantly related to higher room prices (Rivera, 2002) and higher occupation rates (Font, 2002) relative to hotels which are not members of the ecolabel.

The strength of these reputation premiums reported by empirical evidence might depend on the credibility and diffusion of information released by ecolabels[8]. Credibility of the information released by ecolabels is crucial, since ecolabeling is in danger of being considered a green wash (Font, 2002). Credibility results from the higher criteria required for qualification[9]; the existence of a procedure to assess the performance of applicants (preferably undertaken by independent third parties); the existence of a monitoring system to ensure that the label is only used by those firms who have earned it and that it is withdrawn if no longer applicable; participation of multiple stakeholders in the design and management of ecolabels; and the public image of the promoting institution[10] (Buckley, 2002; Mihalic, 2000; UNEP, 1998; WTO, 2002). In addition, great efforts are devoted by ecolabels to develop marketing strategies. It is argued that a logo is not sufficient recognition of firms' abatement efforts and that further promotion is required to raise the interest of the demand market (UNEP, 1998; WTO, 2002). This marketing is argued to be easier when ecolabels are in place, by making use of press releases, leaflets, displays, brochures, publications and similar items (Mihalic, 2000; UNEP, 1998).

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[7] Consistent with previous studies in green market demand, we consider imperfectly informed consumers with green preferences (Arora et al., 1995; Brau et al., 2004; Ibanez et al., 2008; Sedjo et al., 2002). Consumers have some capacity to detect greener behavior, as demonstrated by their generation of premiums from green differentiation, but they are not perfectly able to asses the quality of the commodities they purchase.

[8] Ecolabels can provide an opportunity for imperfectly informed consumers to have higher information on the environmental sensitivity of tourism firms before making their final visit (Buckley, 2002; Font, 2002; Sasidharan et al., 2002; UNEP, 1998; WTO, 2002).

[9] Environmental standards to be met to enter an ecolabel are typically higher than those in which firms voluntarily engage in unilateral commitments, since ecolabels should contain substantive criteria that distinguish between firms which have earned the label and those which have not (Buckley, 2002).

[10] The reputation of the promoting institution can increase the confidence on the validity of environmental improvements and of technical consistency (Font, 2002; WTO, 2002).

Overall, it is necessary for an ecolabel to provide services to its members in order to raise credibility and diffusion of information in order to be successful. These services are costly, and thus, obtaining enough founding is one of the threats which ecolabels must face. Funding usually come from the promoting institution, public or private foundations, and fees from applicants (WTO, 1999). The literature on ecolabeling in tourism recognizes the relevance of fees, but it also highly recommends keeping fees as low as possible (Font, 2002; Halme, 2001; UNEP, 1998; WTO, 2002). Thus, a general concern in this literature is the ability of ecolabels to obtain enough members. An ecolabels' ability to do this is highly related to the technical assistance and guidelines that it can provide to firms in order to improve their environmental behavior and to facilitate adherence (Font, 2002; UNEP, 1998; WTO, 2002). The higher the number of adherents, the higher the financial resources of the initiative, and thus, the higher the level of services it provides, which increase the reputation of the scheme. Based on a world-wide survey on voluntary initiatives in tourism, the WTO (2002) concludes that there is a critical mass of 3 to 10 percent of firms operating in a region that must belong to the initiative to make it viable in the long run. These figures constitute the minimum necessary share to credibly present the ecolabel to the tourism market (Font, 2002) and to offer a real consumption choice to the consumer (WTO, 2002).

The last price premium to be considered is the one resulting from increased environmental quality in the region. The tourism literature considers environmental investments for improving environmental quality as non-excludable goods. Then, consistent with empirical evidence, environmentally-friendly strategies positively affect the profits of all firms (Huybers & Bennett, 2002). The strategic consequences of the existence of this premium in tourism have been previously analyzed, mostly in models of environmental competition between destinations (Calveras, 2003, 2007; Calveras & Vera-Hernández, 2005; Candela & Cellini, 2006; González, León, & Padrón, 2006; Pintassilgo & Albino, 2007).

3. The unilateral commitment model

We consider a model where a fixed population of firms $N = \{1,...,n\}$, $n \geq 2$, make use of a common pool renewable natural resource for the recreational enjoyment of their customers. Some examples of what the resource might be are a lake, a piece of shoreline, diving areas, fresh and salt ponds, rivers, caves, forest land, wildlife areas and ski areas (Healy, 1994; Imperial, 1999). Recreational activities have a negative impact on the quality of the resource, but firms can undertake voluntary abatements of their environmental pressures beyond those required by regulation[11].

Similar to Sethi and Somanathan (1996) and Osés and Viladrich (2007), we represent the abatement efforts of each firm $i \in N$ with a binary variable $a_i \in \{a_{ng}, a_g\}$, where a_g corresponds to firms voluntarily undertaking abatement efforts beyond compliance and a_{ng} to firms only complying with regulation ($a_g > a_{ng}$). We refer to agents choosing a_g as "green" firms, which have undertaken unilateral commitments, and to agents choosing a_{ng} as "non-green" firms. For simplicity in notation we normalize a_{ng}=0[12]. The abatement profile of firms, $\bar{a} = (a_1, \ldots, a_n)$, determines the proportion of green firms s_g and that of non-green firms s_{ng} in the population, where $s_{ng}=1-s_g$.

Consistent with empirical evidence in the tourism literature firms' payoffs differ depending on their environmental strategies (Álvarez et al., 2001; Carmona-Moreno et al., 2004; Claver-Cortés et al., 2007; Kassinis et al., 2003). Specifically, some empirical literature (Huybers et al., 2002; Kassinis et al., 2003; PATA, 2007; Rivera, 2002) suggests that this difference can be motivated by a demand effect that generates a competitive/comparative advantage for firms that undertake voluntary environmental actions, and it is usually reflected in the capacity of green firms to charge higher prices. Following this evidence, as first presented in Blanco et al.(2009), we assume that the price at which player i sells its tourism product is equal to:

$$P_i = x + \delta(s_{ng}, K) \cdot g(a_i) + \gamma(K), \text{ for } \forall s_{ng} \geq 0 \tag{1}$$

where x is a part of the price independent of environmental actions and $g(a_i) = \{0,1\}$ is a dummy variable equal to 1 for firms undertaking abatement ef-

[11] To exercise this potential, tourism firms can voluntarily undertake either activities to reduce environmental pressures (as more efficient use of raw materials, reduction of pollution emissions, greener purchasing, etc.) or investments for improving the status of an already degraded environment (being some examples a hotel improving the quality of a beach next to it or a coral reef excursions company cleaning its diving area) (Mihalic, 2000).

[12] Thus, we consider positive reductions in environmental pressures as participation in a unilateral commitment. Other more complex specifications would be possible. For example, a_g could result from profit maximization by firms in a model where premiums from green differentiation also depend on a firm's abatement efforts $\delta(s_{ng},K,a_g)$. Assuming $\partial\delta(\cdot)/\partial a_g > 0$, $\partial^2\delta(\cdot)/\partial a_g^2 < 0$, and $c''(a_g)$>0, the symmetric level of a_g selected by firms would be the result of $\frac{\partial\delta(\cdot)}{\partial a_g} = c'(a_g)$. A second possibility is that the level of a_g is determined by a code of good practices developed by an industry association. In that case, the process of signing-up to the code and abatement decisions by firms should be modeled separately (as in Dawson et al., 2008).

forts beyond of those legally required ($0<a_i<1$) and equal to 0 for non-green firms. Attributes defining $\delta(s_{ng},K)$ and $\gamma(K)$ are,

$$\delta(s_{ng},K)=\begin{cases} z_i \geq 0 & if\ s_{ng}=1 \\ 0 \leq \delta(\cdot) \leq z_i & if\ 0<s_{ng}<1 \\ 0 & if\ s_{ng}=0 \end{cases}$$

$$\text{and}\ \frac{\partial \delta(\cdot)}{\partial s_{ng}}>0,\ \frac{\partial^2 \delta(\cdot)}{\partial s_{ng}^2}<0,\ \lim_{s_{ng}\to 0}\delta(\cdot)=0$$

$$\delta(s_{ng},0)=0, \qquad \text{and}\ \frac{\partial \delta(\cdot)}{\partial K}>0,\ \frac{\partial^2 \delta(\cdot)}{\partial K^2}<0$$

$$\gamma(0)=0, \qquad \text{and}\ \frac{\partial \gamma(\cdot)}{\partial K}>0,\ \frac{\partial^2 \gamma(\cdot)}{\partial K^2}<0$$

These establish that when player i undertakes voluntary environmental actions, it is capable of charging a price premium $\delta(\cdot)$, thanks to its environmental differentiation. Differentiation is higher when the proportion of non-green firms (green firms) is higher (lower) in a region. Furthermore, the price premium $\delta(\cdot)$ only takes positive values for positive levels of natural capital in the region and is increasing with the environmental quality of the natural CPR of which firms make use. This positive relationship can be justified either by a higher concentration of more environmentally aware visitors in regions highly-endowed with natural resources or by tourists being more concerned for their environmental pressures in areas with high environmental quality.

In addition, we consider a second price premium $\gamma(\cdot)$ that positively depends on environmental quality and that is common to all firms regardless of their individual environmental behavior. This premium reflects both the non-excludable character of the resource, which is a property of common pool resources, and the fact that environmental amenities constitute a component of the tourism product in nature-based destinations. Some empirical evidence shows that tourists are ready to pay higher prices for higher levels of environmental quality at a tourism destination (Alegre & Cladera, 2006; Alegre & Juaneda, 2006; Huybers et al., 2003).

Building on equation 1, the following payoff function can be constructed:

$$\pi_i = q_i[x+\delta(s_{ng},K)\cdot g(a_i)+\gamma(K)]-c(a_i)-co \qquad (2)$$

where q_i is the quantity produced by the i-th firm, which, for simplicity, is assumed to be 1; co are costs independent of environmental behavior and $c(a_i)$ is the cost of abatement activities. We assume $c(0)=0$, $c'(a_i)>0$, $\lim_{a_i \to 1} c(a_i) = \infty$. Thus, only green firms incur abatement costs.

For a given level of capital endowment, payoffs for firms following each strategy depend on the composition of the population. According to evolutionary game theory, payoff differentials exert evolutionary pressures on the population composition to evolve in favor of those groups earning the highest payoff. That is to say, firms respond to differences in payoffs by modifying their strategies. This behavioral pattern does not change instantaneously. This is modeled using the replicator dynamics, which is the simplest evolutionary dynamic one can use to investigate dynamic properties of evolutionary stable strategies (Mailath, 1998; Sethi et al., 1996)[13]:

$$\dot{s}_{ng} = s_{ng}\left(\pi_{ng} - \bar{\pi}\right) \tag{3}$$

where $\bar{\pi}$ is the average payoff in the population as a whole, $\bar{\pi} = s_{ng}\pi_{ng} + (1 - s_g)\pi_g$. Combining equations 2 and 3 the replicator dynamics can be specified as:

$$\dot{s}_{ng} = s_{ng}(1 - s_{ng})[c(a_g) - \delta(s_{ng}, K)] \tag{4}$$

Note that since all firms benefit from premiums from increased environmental quality, $\gamma(\cdot)$ does not influence the evolution of the composition of the population.

To model the renewable natural resource**,** we assume that environmental quality varies over time according to the following motion function:

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[13] Given its mathematical expression there are several implicit assumptions. First, the replicator dynamics assumes a well-mixed constant population with a finite number of strategies and posits that the growth rate of shares of strategies in the population is proportional to its success (Nowak et al., 2004). Assuming a constant population makes sense in conservation areas, where a fixed total number of licenses to operate are given or in mature tourism destinations, where a maximum number of rooms or in recreational services might have been reached.

Second, the replicator equation describes selection, no drift and no mutation (Nowak et al., 2004). As a consequence, a strategy missing in the initial population remains absent. However, it is usual to investigate the impacts on the dynamic system resulting from the introduction of a new strategy.

Third, the proportion of individuals choosing a particular behavior increases when the payoff to that behavior exceeds the average payoff in the population and decreases when the reverse is true (Sethi et al., 1996). This conforms to the adoption decisions of firms being likely to be influenced by the norms set by other firms in the industry, originating either a demonstration effect or peer pressure (Anton et al., 2004). In economics, it is usual to motivate change in strategies on that successful behavior becomes more prevalent because market forces select against unsuccessful behavior and because agents imitate successful behavior (Mailath, 1998).

$$\dot{K} = F(K) - D(s_{ng}), \tag{5}$$

where $F(K)$ is a replenishment function and $D(s_{ng})$ is the total environmental damage by the population of firms.

We consider a differentiable replenishment function, *F(K)*, satisfying the usual assumptions for describing the dynamics of renewable resources, as represented in figure 1. There is a finite carrying capacity $\overline{K}$ of the resource and a minimum level of natural capital $\underline{K}$ $(0 < \underline{K} < \overline{K})$ so that $F(\overline{K}) = 0$ and $F(\underline{K}) = 0$. Between $\overline{K}$ and $\underline{K}$, the resource grows at a positive rate, and it grows at a negative rate otherwise. This describes the fact that the resource reaches a maximum size $\overline{K}$ and that below $\underline{K}$ replenishment via natural reproduction is impossible even in the absence of environmental damage. For stock levels between $\underline{K}$ and $\overline{K}$ $F''(K)>0$, with $F(K)$ reaching its maximum at K^M.

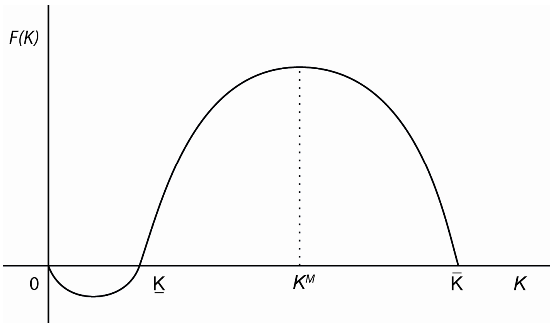

Fig. 1. Replenishment function of the CPR.

Regarding environmental damage, we attribute a uniform environmental damage d to each firm, which can be reduced by abatement efforts. Each firm's strategy selection determines its environmental damage, net of abatement, which is d for non-green firms, and $d(1\text{-}a_g)$ for green firms. Given our specifications, abatement is open to two different interpretations, either reduction in the environmental pressures (more efficient use of natural inputs or reductions in pollution emissions) or direct investments toward improving the quality of the natural resource. Then, after some straightforward transformations, total environmental damage is $D(s_{ng}) = N[1 - a_g(1 - s_{ng})]$, where d is normalized to one without loss of generality[14].

[14] Initial specification of total damage is $D(s_{ng}, s_g) = N \cdot d[s_{ng} + s_g(1 - a_g)]$.

3.1. Population Dynamics

Let us now present the population dynamics when endowment of natural capital in the region is exogenous. Apart from the usefulness of this exercise for later sections, this case could be empirically relevant for those contexts where, due to scale properties, the activity of the model's population as a whole has no noticeable effect on the quality of the resource.

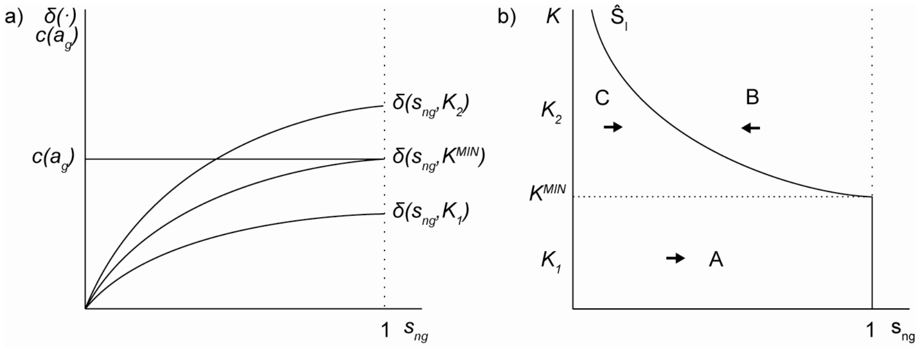

Fig. 2. Population dynamics of the unilateral commitment model.

With exogenous natural capital, the dynamics of the system is fully described by equation 4. It is easy to verify that there are three steady states: (i) no firms engage in voluntary environmental action, $s_{ng}=1$; (ii) all firms undertake voluntary abatements, $s_{ng}=0$; and (iii) firms are indifferent between being green or non-green, that is, when $\delta(s_{ng},K)=c(a_g)$.

Lemma 1: *For a given level of natural capital, a heterogeneous equilibrium of the population composed of non-green and green firms exists if there is a* $s_{ng} \in (0,1)$, *such that* $\delta(s_{ng},K)=c(a_g)$. *Given that this equilibrium exists it is always asymptotically locally stable. A stable homogeneous all-non-green firms equilibrium exists when* $\delta(1,K) < c(a_g)$. *Any homogeneous all-green equilibrium is unstable.*

In figure 2.b, $\hat{S}_I$ (for which $\dot{s}_{ng} = 0$) represents the steady state levels of s_{ng} for different levels of K. Given the properties of $\delta(\cdot)$this curve shows asymptotic convergence to the vertical axis. As it is shown, there is a level of environmental capital K^{MIN} below which price premiums for green differentiation are lower than extra abatement costs for any population composition, that is, $\delta(1,K^{MIN})=c(a_g)$. Then, below K^{MIN} (area A in figure 2.b), $\dot{s}_{ng} < 0$ and, therefore, only homogeneous equilibria with all-non-green populations can be stable.

For natural endowments above K^{MIN}, only heterogeneous equilibria are stable. In Area B in figure 2 the proportion of green firms is small enough to make being green profitable, and the dynamics imply a shift of the population toward an increase in this strategy (a fall in s_{ng}). However, when the proportion of green firms is high (area C in figure 1), premiums from green differentiation are too low to make this strategy profitable and convergence to the steady state implies a fall in the proportion of green firms (an increase in the proportion of non-green firms).

Some empirical evidence (Álvarez et al., 2001; Claver-Cortés et al., 2007; Kassinis et al., 2003; Rivera, 2002) shows that green firms obtain statistically significant better economic results than other firms at nature-based destinations. In the context of our model, the cases analyzed by this literature would be located in area B and therefore would reflect incomplete adjustment to the steady state.

3.2. Resource Dynamics

Let us now analyze the dynamics of the natural resource when the composition of the population is exogenous. According to equation 5, the condition for constant capital is $D(s_{ng})=F(K)$. This defines a relationship between the composition of the population and the stock of natural capital as shown in the forth quadrant of figure 3, where curves $\tilde{K}(s_{ng})$ and $\hat{K}(s_{ng})$ represent the isoclines of the resource ($\dot{K}=0$). This relationship is obtained using the steady state relationship between environmental damage and natural capital (first quadrant) and that between total damage and the composition of population (third quadrant), and it is drawn for the special case when the natural capital in the steady state is positive even in the more polluting scenario (that is, when s_{ng}=1)[15].

When analyzing the dynamics of the resource for an exogenous s_{ng}, it has to be first noted that the replenishment function is defined such that there is a threshold, $\underline{K}$ below which the resource is doomed to exhaustion regardless of the environmental pressures (area A). Moreover, if natural capital reaches a level between $\underline{K}$ and $\tilde{K}(s_{ng})$, exhaustion is not inevitable but it is not possible to achieve levels of damage low enough to avoid exhaustion with only voluntary environmental behavior as defined in the model. When natural capital is between $\tilde{K}(0)$ and $\hat{K}(0)$, it is possible to avoid exhaustion through voluntary environmental behavior by at least a proportion of the firms. For levels of natural capital above $\hat{K}(0)$, disregarding the composition of the population, environmental damage is higher than the

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[15] As non-green firms are those that just meet with environmental regulation, this amounts to say that environmental regulation in place prevents exhaustion at least for certain initial levels of natural capital and *n*. It is quite straightforward to extend the analysis to cases when regulation is not tight enough to prevent exhaustion for any initial level of natural capital or *n*.

replenishment capacity of the resource, and thus K converges to the isocline $\hat{K}(s_{ng})$.

Lemma 2: *$\hat{K}(s_{ng})$ and $\tilde{K}(s_{ng})$ represent curves of equilibria of the resource dynamics. $\hat{K}(s_{ng})$ determines asymptotically locally stable equilibria, for which there is a negative relationship between environmental damage and steady state natural capital, while $\tilde{K}(s_{ng})$ represents unstable equilibria, characterized by a positive relationship between environmental damage and steady state natural capital.*

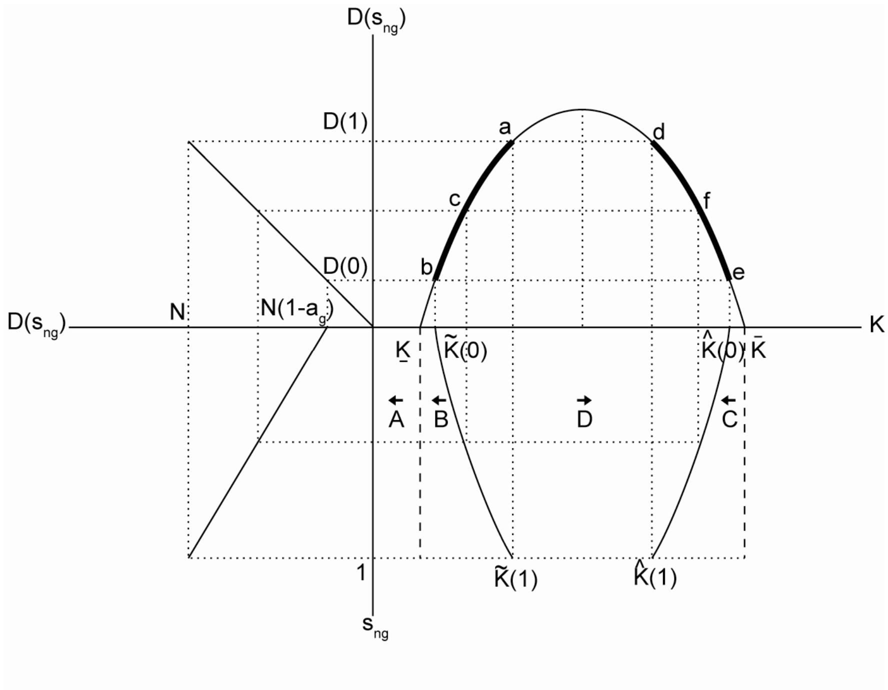

Fig. 3. Resource dynamics of the unilateral commitment model.

3.3. Dynamics of the combined system

In this section both natural capital and the composition of the population are endogenous, and, therefore, dynamics are determined by the system formed by equations 4 and 5. As usual, we first explore the steady states (s_{ng},K) of our dynamic system. It is shown that in this system, as in Osés and Viladrich (2007), and opposite to Sethi and Somanathan (1996), the resource dynamic play a key role in determining the population composition in the steady state.

Superimposing figure 2.b and the fourth quadrant of figure 3 yields figure 4, where different scenarios are represented in terms of the number and stability of the steady states. Existence and stability of different types of equilibria for the combined system are formalized in a series of propositions (proofs can be found in appendix I).

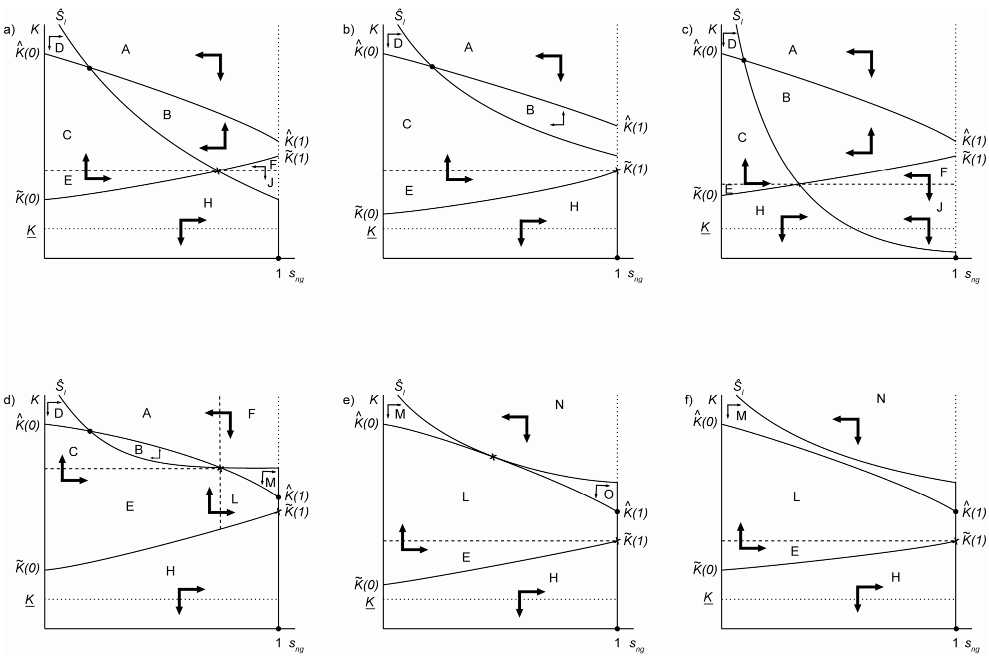

Fig. 4. Dynamics of the combined system of the unilateral commitment model.

Proposition 1: *Whenever there exists a value of* $s_{ng} \in (0,1)$ *such that the isocline of the population shares at least one point with any of the isoclines of the natural capital, a mixed equilibrium of the combined system exists. Given that a heteroge-*

neous equilibrium exists, conditions for that equilibrium to be asymptotically locally stable are F'(K)<0 and $\frac{\partial\delta(s_{ng},K)}{\partial s_{ng}} + \frac{N \cdot a_g}{F'(K)} \frac{\partial\delta(s_{ng},K)}{\partial K} > 0$.

Figures 4.a-e represent scenarios where at least one heterogeneous equilibrium exists, whereas in figure 4.f no heterogeneous equilibrium exists. Stable (unstable) equilibria are represented by a solid dot (a cross). Condition *F'(K)<0* says that stable heterogeneous equilibriums must belong to the isocline $\hat{K}(s_{ng})$, whereas the second condition in proposition 1 implies that a marginal increase in the proportion of non-green firms has a negative effect on these firms' profits compared to the green firms' profits ($\partial(\pi_{ng} - \pi_g)/\partial s_{ng} < 0$). It also implies that $\hat{K}(s_{ng})$ must be flatter than the isocline of the population at the intersection point[16].

Whenever a stable heterogeneous equilibrium exists, areas A to C in figures 4.a-d represent the set of initial situations for which convergence towards the stable heterogeneous equilibrium is guaranteed, i.e., its basin of attraction. Area A describes values of the system for which the natural resource is abundant and the number of firms undertaking voluntary environmental abatement is small. Therefore, firms can charge high price premiums for green differentiation when undertaking voluntary environmental initiatives, *δ(·)*, which are higher than abatement costs to becoming green. As a result, the number of green firms increases. In addition, given that area A is above $\hat{K}(s_{ng})$, total damage exercised by users exceeds the replenishment capacity of the resource, $D(s_{ng})>F(K)$, and, consequently, the stock of natural capital diminishes. The initial scenarios in area B are similar to those in are A, but in B the stock of natural capital is lower, thus the replenishment capacity of the resource is higher and the resulting dynamic is an increasing stock of natural capital. In area C, as in B, environmental damage is below the replenishment capacity of the resource but, in this case, the combination of the stock of natural capital and the proportion of green firms in the population does not create sufficiently high price premiums for green differentiation. Thus, green firms have incentives to abandon their environmental efforts and become non-green. Area D presents an extreme situation in which both environmental quality and the proportion of green firms are very high. For values in area D, there are too many green firms in the system for green differentiation to be profitable, and hence the number of green firms diminishes. Further, the high stock of natural capital in D determines a small replenishment capacity of the resource which is actually smaller

[16] Since condition (1.ii) is equivalent to $-\frac{\partial\delta(\cdot)/\partial s_{ng}}{\partial\delta(\cdot)/\partial K} > \frac{N \cdot a_g}{F'(K)}$, for *F'(K)*<0.

than damage derived from recreational uses. Therefore, environmental quality is reduced.

For other sets of initial values, such as those included in areas *E* to *G*, the qualitative analysis does not allow us to unambiguously determine the equilibrium towards which trajectories converge. In any other areas, the system inevitably converges to a stable all-non-green equilibrium. Existence and stability of all-non-green homogeneous equilibria are presented in proposition 2.

Proposition 2: *The point $(s_{ng},K)=(1,0)$ is an asymptotically locally stable equilibrium with all-non-green firms. There exist homogeneous equilibria with all-non-green firms and positive natural capital whenever the isocline of the population shares one point with any of the isoclines of the natural capital for $s_{ng}=1$. Given that an homogeneous equilibrium with all non-green firms and positive natural capital exists, it is a necessary and sufficient condition for the equilibrium to be asymptotically locally stable that $F'(K)<0$ and $\delta(1,K)<c(a_g)$.*

This implies stronger conditions than in Osés and Viladrich (2007) where all-non-green equilibria are always stable except in the special case when $\tilde{K}(1)=\hat{K}(1)$. In our case, for these equilibria to be stable it is necessary that the slope of the resource replenishment function is negative ($F'(K)<0$) and that a shift to the green option is not profitable even when the potential premium is the highest for a given level of capital ($\delta(1,K)<c(a_g)$).

Therefore, there are two relevant thresholds of natural capital, which affects the stability of equilibria for all-non-green populations. First, below $\underline{K}$, the natural capital is inevitably depleted regardless of the damage exercised by users. The existence of this threshold guarantees that (1,0) is always asymptotically locally stable. Areas H and J in figure 4 determine values of the system for which the system necessarily evolves towards the equilibrium (1,0). The second relevant threshold for stability is K^{MIN}. Recall that the value of natural capital K^{MIN} is the threshold above which users of the natural resource start to find it worth becoming green when starting from an all-non-green situation. It is necessary that $K^{MIN} > \hat{K}(1)$ for an asymptotically locally stable equilibrium with all-non-green firms and positive natural capital to exist. Figures 4.d to f represent situations in which these equilibria are stable. In these figures, areas L to O determine the areas of convergence to this equilibrium.

Lastly, opposite to Osés and Viladrich (2007) and as stated in lemma 1, all-green homogeneous equilibria are not stable. This is because $\widehat{S}_1$ approximates asymptotically to the vertical axis. This asymptotic behavior is independent of the dynamics of natural capital.

Proposition 3. *Endogenizing natural capital does not change the stability conditions for all-green equilibria. These are always unstable.*

In sum, in the combined system, there always exists an asymptotically locally stable all-non-green equilibrium in which the resource is depleted, (1,0). In addition to this equilibrium: (i) an asymptotically locally stable all-non-green homogeneous equilibrium can exist when $\hat{K}(1) < K^{MIN}$, for which the resource is not depleted, (1, $\hat{K}(1)$); (ii) an asymptotically locally stable heterogeneous equilibrium can exist when there exists a $s_{ng} \in (0,1)$, for which $\widehat{S}_I = \hat{K}(s_{ng})$ and the slope of $\widehat{S}_I$ is higher than the slope of $\hat{K}(s_{ng})$ in absolute terms.

The existence of a basis of attraction to the heterogeneous green-non-green equilibrium only under certain situations is consistent with the observation that firms making use of some natural CPRs engage in voluntary initiatives whereas firms using other CPRs do not. The historical evolution of tourism destinations shows that, initially, the tourism industry had no particular concern for its environmental impacts, thus being in an all-non-green equilibrium. Tourism expansion has generally been described as accompanied by congestion, degradation of natural assets, weak management of wastes and effluents and other negative impacts (for some examples, see Knowles & Curtis, 1999; Morgan, 1991; Tisdell, 2001). The homogeneous all-non-green firms equilibrium has shown itself to be a stable equilibrium of the system in some destinations where environmental concerns have not been introduced, whereas in other destinations the population has evolved to include a certain proportion of green firms. When the all-non-green equilibrium is unstable, the introduction of a green strategy by a single firm entails a trajectory that converges to the equilibrium with a heterogeneous composition of the population. This conforms to the increasing environmental concerns shown in some destinations, in spite of the fact that such concerns are embraced only by a certain share of its tourism firms (UNEP, 1998; WTO, 2002).

4. The ecolabel and unilateral commitment model

This section extends the model presented in section 3 to introduce a new strategy into the system: an ecolabel to which firms can voluntarily adhere. Conventional practice in evolutionary game theory is to conceptualize the creation of new strategies as exogenous mutations with a very small initial frequency (Nowak et al., 2004). This makes sense in biological games in which populations evolve through mutations, and in some economic games, such as innovative entrepreneurial behavior. However, other scenarios for initial membership to the ecolabel are more reasonable in our game. The process of the creation of an ecolabel is neither random nor the result of individual entrepreneurial behavior. Instead, it seems more realistic to assume that the design of the ecolabel is a process in which subsets of firms undertake an active role in collaboration with other stakeholders, such as the government or non-government organizations. For example, in 2002, it was reported that 2/3 of the existent ecolabels in tourism were coordinated with multistakeholder groups representing tourism, environmental, social and consumers' interests (WTO, 2002). Moreover, empirical data show that voluntary tourism initiatives are led by tourism NGOs (in 32% of the cases), government organizations (20%), private companies (15%), and other NGOs (33%) (WTO, 2002). Further, industry associations also exhibit environmentally pro-active behavior, as shown by 11 out of the 28 ecolabels in the UNEP (1998) study being promoted by industry associations.

It is beyond the scope of this paper to model the collective action processes by which firms coordinate among themselves and/or with other stakeholders to create an ecolabel. We rather analyze the endogenous responses of individual firms to the exogenous creation of an ecolabel in the system. We will show that this response critically depends on the number of firms that act as promoters of the ecolabel, the type of firms acting as promoters, the initial composition of the population, the institutional design of the ecolabel and the initial level of environmental quality.

As in section 3, we first present the model and analyze the population dynamics and the dynamics of natural capital separately. After this, the combined system is studied.

When extending the model to consider the existence of an ecolabel for the population of firms making use of the CPR, we assume that firms that adhere to the ecolabel incur higher abatement costs in exchange for the capacity to charge a higher price. The payoff function that substitutes equation 2 is now equation 6:

$$\pi_i = q_i[x + \delta(s_{ng}, K)\cdot g(a_i) + R(s_l, K)\cdot l(a_i) + \gamma(K)] - c(a_i) - co\,,\quad i = ng, g, l \tag{6}$$

$R(0,K) = 0$, and $\dfrac{\partial R(\cdot)}{\partial s_l} > 0$, $\dfrac{\partial^2 R(\cdot)}{\partial s_l^2} < 0$

$R(s_l, 0) = 0$, and $\dfrac{\partial R(\cdot)}{\partial K} > 0$, $\dfrac{\partial^2 R(\cdot)}{\partial K^2} < 0$

$a_l > a_g > a_{ng}$

where $a_i \in \{a_{ng}, a_g, a_l\}$ are abatement efforts, with $a_l \in (0,1)$ being the one required by the ecolabel rules, and $s_i \in \{s_{ng}, s_g, s_l\}$, $\sum s_i = 1$ represents the proportion of each of the three kinds of firms in the population. $l(a_i) = \{0,1\}$ is a dummy variable taking the value 1 for ecolabel firms and 0 otherwise. Abatement efforts undertaken by non-green firms are normalized to zero as in the previous version of the model.

According to the previous expression, payoff functions of green and non-green firms do not change compared to the model in section 3. Regarding the firms that

adhered to the ecolabel, we assume that they obtain the same price premium based on differentiation as those firms that unilaterally carry out abatement activities. In addition, ecolabel firms can charge an additional price premium *R(·)* that depends upon the reputation of the ecolabel. We assume that this premium depends on the number of firms adhered to the initiative and on the environmental quality of the CPR. As explained in section 2, as more firms adhere to the ecolabel, the ecolabel gains greater funding capacity to provide the exogenous services that increase its reputation premium. As to the positive dependence on environmental quality, the arguments are the same as those put forward in section 3 for $\delta(\cdot)$. We also reasonably assume that the premium is zero when there is no firm participating in the initiative and when the natural resource is exhausted.
As already noted, it is reasonable to assume that those firms that adhere to the ecolabel have to bear higher environmental costs compared to firms following other strategies. One reason for this is that their abatement efforts are usually greater since, according to the international standard for eco-labels (ISO 14024), these voluntary initiatives should include the precondition of the applicant's compliance with environmental legislation and show measurable and significant differences in environmental impact compared to non-certified licensees (WTO, 2002). Apart from this, there are other costs associated with ecolabel membership, such as certification and licensing fees to be paid to the ecolabelling agency for awarding the ecolabel to firms (Anton et al., 2004; Arimura, Hibiki, & Katayama, 2008; Sasidharan et al., 2002), and greater coordination activities or employee training and product and process improvement (Anton et al., 2004). For simplicity, we do not model these other costs explicitly.

The population dynamics determined by a two-dimensional dynamic system in the variables s_{ng} and s_l are shown in equations 7 and 8:

$$\dot{s}_i = s_i\left(\pi_i - \overline{\pi}\right),\ i=l,ng \tag{7}$$

$$\left.\begin{aligned} \dot{s}_{ng} &= s_{ng}[-s_l\left(R(s_l,K)-\left(c(a_l)-c(a_g)\right)\right)-(1-s_{ng})\left(\delta(s_{ng},K)-c(a_g)\right)] \\ \dot{s}_l &= s_l[s_{ng}\left(\delta(s_{ng},K)-c(a_g)\right)+(1-s_l)\left(R(s_l,K)-\left(c(a_l)-c(a_g)\right)\right)] \end{aligned}\right\} \tag{8}$$

where average payoffs are now $\overline{\pi} = s_{ng}\pi_{ng} + s_l\pi_l + (1-s_{ng}-s_l)\pi_g$.

As to the natural resource, we assume the same dynamic equation 5, and replenishment function as were put forth in section 3. The damage function now takes into account the existence of a third strategy with differentiated abatement levels, and it therefore becomes the following:

$$D(s_{ng},s_l) = N[(1-a_g)+s_{ng}a_g - s_l(a_l - a_g)] \tag{9}$$

4.1. Population dynamics

When we consider that natural capital is exogenous, the behavior of the system is solely determined by equation system 8. The first quadrant of figure 5 represents a possible configuration of steady states of the system.

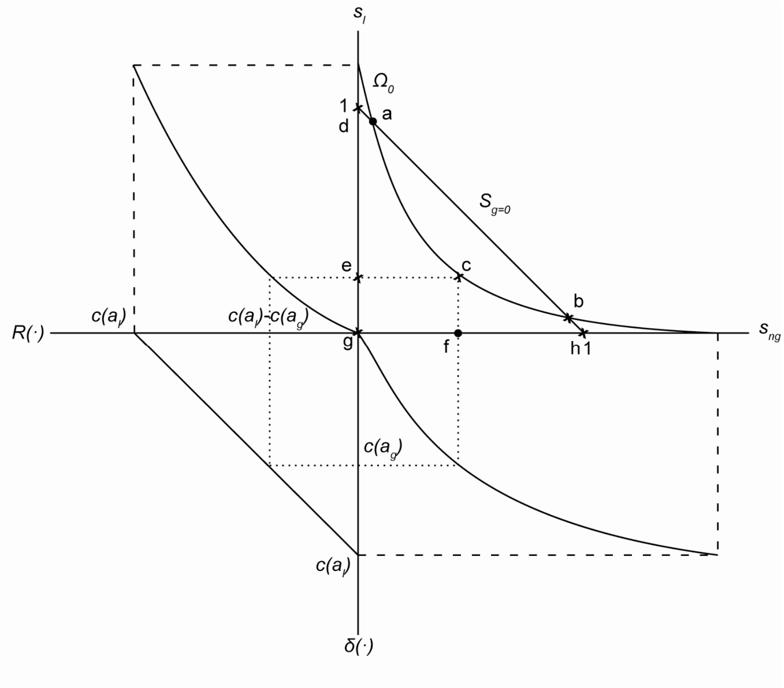

Fig. 5. Equilibrium configuration of the population in the ecolabel and unilateral commitment model.

This figure represents a case where all possible equilibria[17] are present. Line $S_{g=0}$ represents situations where $s_g = 0$ and delimits, jointly with the axis, the feasible region. The curve Ω_0 represents compositions of the population for which payoffs for ecolabel firms and non-green firms are equal. This curve is obtained using the $R(\cdot)$ and $\delta(\cdot)$ functions (second and fourth quadrants, respectively) and the condition of equality between payoffs of ecolabel and non-green firms (third quadrant).

[17] In this section we only deal with hyperbolic equilibria. Non-hyperbolic equilibria are considered when presenting the sensitivity and bifurcation analysis at the end of this section.

Other configurations of the parameters can lead to a different number of steady states, as is shown in figure 6. Still, there are several equilibria that are always present, as is stated in the following lemma (proofs to all lemmas in this section are included in appendix II):

Lemma 3: *Homogeneous all-ecolabel, all-green and all-non-green firms are always possible equilibria. An all-ecolabel equilibrium is asymptotically locally stable when* $R(1,K) > c(a_l)$ *; an all-green equilibrium is always unstable; and an all-non-green equilibrium is asymptotically locally stable when* $\delta(1,K) < c(a_g)$.

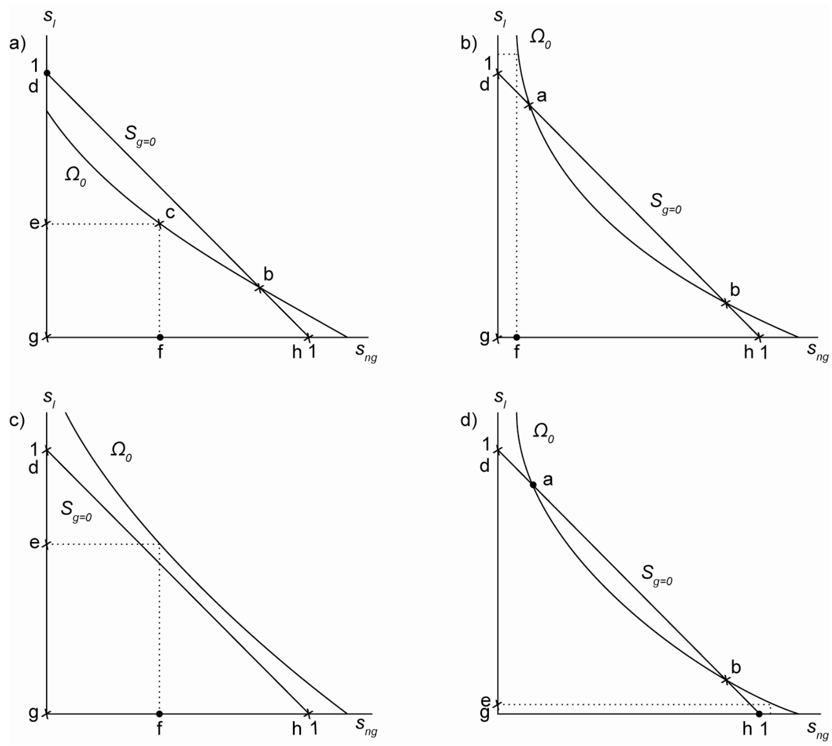

Fig. 6. Other equilibrium configurations of the population in the ecolabel and unilateral commitment model.

Given the nature of the replicator dynamics at points *d*, *h* and *g* of figures 5 and 6, the system is in equilibrium. Figure 6.a represents the optimistic case[18] in which *d* is a stable equilibrium of the system, whereas figure 6.d represents a stable equilibrium *h*. Note that the condition for a homogeneous all-non-green firms equilibrium being stable does not vary with the introduction of the ecolabel.

The relevance of an all-ecolabel equilibrium should be cautiously considered since there is no evidence supporting full adherence to ecolabels in tourism. This can be attributed either to systems being in early stages of dynamic evolutions that eventually would reach a stable point *d*, or to costs associated with certification of ecolabels being above the $c(a_l)=R(1,K)$ threshold. The former hypothesis could be supported by more than half of the ecolabels that were identified by the WTO (2002) as operating for less than four years. This is a rather short time period for the diffusion of a new strategy. Thus, it could be the case that some ecolabels could eventually embrace all firms of their target population. It has been defended that the end point in the evolution of a tourism ecolabel is when it becomes a routine part of normal business relations between firms and customers so that connotations of a label are lost and the criteria of the ecolabel are perceived as a requirement (Buckley, 2002). Buckley (2002) notes that, unlike the case of tourism, there are standards of ecolabels on manufactured consumer goods that are required by consumers or adopted by legal mandates in many countries.

In addition to homogeneous populations, the system can have equilibria where two strategies coexist in the long run. Conditions for the existence and stability of these equilibria are presented in lemmas 4 and 5.

Lemma 4: *An equilibrium of the population composed of non-green and green firms exists if there exists a* $s_{ng} \in (0,1)$ *such that* $\delta(s_{ng},K)=c(a_g)$. *Given that it exists, it is always asymptotically locally stable and it is monotonically convergent. An equilibrium of the population composed of ecolabel and green firms exists if there exists an* $s_l \in (0,1)$ *such that* $R(s_l,K)=c(a_l)-c(a_g)$. *Given that it exists, it is always unstable. Equilibria of the population composed of ecolabel and non-green firms exist if* Ω_0 *and* $S_{g=0}$ *share at least one point. This is a locally asymptotically stable equilibrium if* $\delta(s_{ng},K)<c(a_g)$ *and* $\frac{\partial R(\cdot)}{\partial s_l} < \frac{\partial \delta(\cdot)}{\partial s_{ng}}$ *and it is always monotonically convergent.*

[18] Throughout the paper we will be labeling cases as optimistic or successful when the ecolabel can survive in the long run. However, it must be noted that evaluating a voluntary program on the basis of participation alone is inappropriate. Even with very high participation rates, aggregate abatement can be very low if abatement by each participating firm is low (Alberini et al., 2002).

Figure 6.c represents a pessimistic case in which Ω_0 never crosses $S_{g=0}$. In this case, there is no other stable equilibrium but *f*, which corresponds to the heterogeneous equilibrium of the system in section 3.1 composed of green and non-green firms, as expressed in lemma 1. Then, in figure 6.c, the ecolabel has no possibility of success since it does not change the long-term behavior of the population with respect to the situation where only unilateral commitments were possible. In figures 5 and 6, points *a* and *b* are equilibria where heterogeneous populations of ecolabel and non-green firms exist. Point *b* in figure 5 is an unstable equilibrium, whereas *a*, where the proportion of ecolabel firms is higher, is stable. However, it can also be the case that point *a* is unstable as represented in figure 6.b. Consequently, figure 6.b represents another pessimistic case in which, even though equilibria where a positive proportion of firms adhere to the ecolabel exist, they are not stable.

Finally, lemma 5 deals with the case of heterogeneous equilibrium with all three kinds of agents:

Lemma 5: *A heterogeneous equilibrium where the population is composed of ecolabel, green and non-green firms exists if the values of* s_l *such that* $R(s_l, K) = c(a_l) - c(a_g)$ *and* s_{ng} *such that* $\delta(s_{ng}, K) = c(a_g)$ *meet the condition* $0 < s_l + s_{ng} < 1$. *This equilibrium is a saddle point.*

Point *c* in figure 5 represents this equilibrium. This is an equilibrium because at point *c,* profits from all three strategies are equal. Point *c* belongs to curve Ω_0, and thus, in it, $\pi_l = \pi_{ng}$. In addition, as determined in the second quadrant, in point *c,* the reputation strictly compensates for the extra cost of being an ecolabel with respect to being green ($R(\cdot)=c(a_l)-c(a_g)$), which determines $\pi_l=\pi_g$. Moreover, as can be seen in the fourth quadrant, premiums from environmental differentiation strictly compensate for abatement costs of the unilateral commitment ($\delta(\cdot)=c(a_g)$). Consequently, $\pi_g=\pi_{ng}$. Even though this equilibrium can exist, it is just conditionally stable and there is only one trajectory that leads to it (the stable arm). Equilibrium *c* plays the important role of delimiting the basin of attraction for equilibria with and without ecolabel membership, as is shown in the following analysis.

Dynamics: some scenarios of the creation of an ecolabel.

Let us now explore some scenarios that seem appropriate when analyzing the institutional change that implies the creation of an ecolabel in a tourism region. These scenarios would be related to invasibility concerns in evolutionary game theory. When an equilibrium is locally asymptotically stable, then in every open neighborhood of this equilibrium, every path sufficiently close to the equilibrium converges to it (Friedman, 1998; Nowak et al., 2004). However, if the initial frequency of the new strategy exceeds a certain "invasion barrier," the new strategy can spread and eventually eliminate the original strategies (Nowak et al., 2004). This idea of a minimum number of firms necessary to join a voluntary agreement, which is endogenously determined, is similar to the analysis undertaken by Dawson and Segerson (2008), which the authors relate to the notion of the "minimum contributing set" advocated as a solution to the public goods problems. We consider in this section some initial states of the creation of the ecolabel, in a non-exhaustive manner, and analyze the resulting dynamics. Argumentation on dynamics is based on figure 7, where a stable heterogeneous equilibrium exists with ecolabel firms.

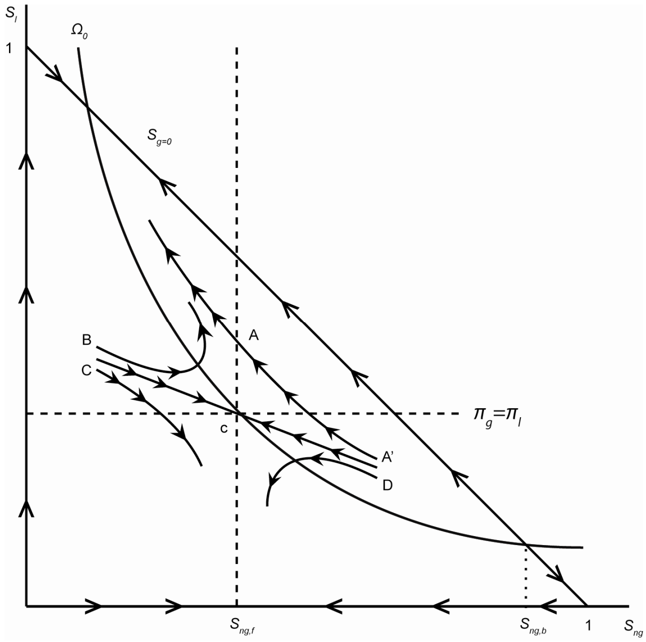

Fig. 7. Population dynamics of the ecolabel and unilateral commitment model.

First, let us start by considering an initial system that has reached equilibrium *f*, where green and non-green strategies coexist. In this situation, let us assume that, as reported by Mihalic (2000), some tourism firms realize that unilateral commitments are of limited marketing value in fostering environmental competitiveness, and consequently they consider the option of obtaining recognized certification of their environmental behavior. Consequently, let us assume that a subset of the green firms in the system coordinate to create an ecolabel, possibly with the participation of a third party that gives written assurance of conformance to the specified requirements to join the initiative. This picture is consistent with the observation that the tourism industry has usually preferred to develop its own certification systems (Font, 2002). Some ecolabels are actually promoted by clusters of environmentally sensitive firms whose aim is to improve the perception of the demand market of their voluntary action (UNEP, 1998; WTO, 2002). In figure 7, an ecolabel created by a coordination process among green firms is represented by a vertical movement from *f* of the population configuration. The proportion of non-green firms does not vary whilst the proportion of ecolabels increases. In that case, a necessary and sufficient condition for the ecolabel to succeed (that is, for the system to converge to the equilibrium with ecolabel firms, *a*) is that the proportion of promoters of the ecolabel is above the value of s_l for which $R(\cdot)=c(a_l)-c(a_g)$, such as point A in figure 7. This requirement implies that for the ecolabel to succeed, it must be more attractive than unilateral commitments from the very onset. That is to say, a minimum threshold of promoters needs to be achieved for the ecolabel to succeed. If this critical level is surpassed, it becomes profitable for additional green and non-green firms to join the ecolabel.

A different situation occurs when coordination to create the ecolabel takes place between a subset of green and non-green firms starting again from *f*. In this case, the initial situation, once the ecolabel is created, would be some point in the area to the left of *c*. For instance, this could be a realistic description of situations in which the ecolabel is launched by an industry association with green and non-green firms (e.g., an association of firms making use of a natural CPR). As explained in section 2, the reputation of an ecolabel depends on the credibility of the information that is provided to the demand market. Subsequently, green firms in the association might be willing to pressure the association to become a promoter of the certification scheme if the tourism association has higher credibility in the sector than other independent third parties. If green firms are dominant in the association, they might be able to force the promotion of the ecolabel by this organization and even make the association force the adherence of non-green firms (for instance, making membership of the association conditional to the adherence to the ecolabel) in order to obtain the critical mass that, as it has been shown, is crucial for the ecolabel's success, or to fully identify the association with the ecolabel. A priori, it could be thought that this second scenario would lead the system to equilibrium *a* more easily than in the first scenario, but this is not the case. It is still possible that the new configuration of the population is on a trajectory that ends in equilibrium *a*, as is the case with point B in figure 7. However, it is also possible that the population moves from *f* to levels of s_l above the s_l for which $R(\cdot)=c(a_l)-c(a_g)$, but that the system moves back to *f*, such as in the trajectory passing by point C. In this scenario, requirements for the ecolabel's not collapsing back to *f* are more stringent than when the promoting firms are only green. This is because, by including non-green firms in the promotion of the ecolabel, price premiums from green differentiation $\delta(\cdot)$, which are common to both environmentally sensitive strategies, decrease. This makes green and ecolabel options less profitable compared to non-green behavior and creates individual incentives to abandon the ecolabel despite its being a better option than unilateral commitments.

Other possible scenarios consider baseline situations where the system is not at point *f* or, put in a different way, where the system developed in section 3 is not in equilibrium. Different situations may arise depending on the baseline composition of the population. Thus, as a third case, let us consider that the ecolabel is created in a very initial phase along the movement from *h* to *f*, more precisely, it is created when $s_{ng,b}<s_{ng}<1$. For example, it could be the case that the CPR under analysis is in a developing country where environmental considerations are not yet widely adopted, with unilateral commitments being present but very limited. In this context, firms might decide to search for private assistance in improving the green image of the region or, alternatively, international organizations might come to the region due to concern about excessive environmental degradation. These external agents might import knowledge from developed countries, where ecolabels are widely used in tourism (UNEP, 1998; WTO, 2002), and propose the creation of a certification program with the purpose of inducing the industry to become more environmentally sensitive. In this context, even in the very favorable situation where these organizations are capable of persuading all green firms to join the certification program, this will not prosper. In this case, the composition of the population moves vertically to $S_{g=0}$. The resulting dynamic converges to an all-non-green firms unstable equilibrium. Not only has the ecolabel failed to get a stable number of participants, but the premature creation of the certification program has also truncated the incipient dynamic of unilateral commitments[19]. The model, therefore, shows that if introduction of certification schemes along the spread of greener behavior in a developing tourism region comes too early, it might be a motivation for its limited success (almost 80% of all ecolabels identified by WTO, 2002 were operating in Europe, and only a few in less developed countries).

This result varies when we consider a fourth case in which the system is moving from the all-non-green equilibrium toward *f*, but has evolved further than in the previous scenario $s_{ng,f}<s_{ng}<s_{ng,b}$. In this case, if the promoting institution is capable of persuading all of the green firms in the region to adhere to the ecolabel, the system moves to $S_{g=0}$ and then along $S_{g=0}$ to the stable equilibrium with the ecolabel (equilibrium *a*). A similar pattern of behavior can arise even if only a subset of green firms act as promoters. To show this, let us consider point A’ in figure 7. At this point, firms that undertake unilateral commitments obtain higher profits than those adhering to an ecolabel, and both strategies are more profitable than non-green. As a result, the proportion of non-green firms decreases since firms move to environmentally-friendlier strategies. During this process, the ecolabel achieves a critical mass of members to become the preferred strategy in the system, and its membership eventually stabilizes at a positive value[20]. The dynamics are, however, dramatically different with a slightly lower level of promoters as

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[19] Given the instability of the homogeneous all-non-green firm situation, it could be expected that the population would eventually again move left along the horizontal axis.

[20] The same qualitative analysis arises when the initial number of promoters already reaches this critical mass, that is, when the initial point is located above $R(\cdot)=c(a_l)-c(a_g)$.

at point D. The ordering of profits is the same, and the ecolabel membership increases in a first stage fed by formerly non-green firms. However, a critical mass to make ecolabelling a preferred option compared to unilateral commitment is never obtained, so the system converges to equilibrium *f* and the ecolabel collapses. Notice that there is a knife-edge initial situation between A' and D for which the system is placed in the stable arm that converges to the equilibrium *c*, where the three types of strategies coexist[21].

Finally, prior to the creation of the ecolabel, the system may be on the left of point *f*. This may happen, for instance, due to an exogenous drop in the level of natural capital[22] (for instance, an oil spill in a coastal tourism area or a fire in a natural hiking area), since this would shift equilibrium *f* to the right. Facing this shock, some firms and/or public agencies may consider the possibility of creating an ecolabel as an instrument to counteract the decline in the environmental image of the region. The creation of the ecolabel puts the system at an initial point belonging to areas to the left of *c*. Thus, it is not sufficient for the proportion of promoting firms to be above $R(\cdot)=c(a_l)-c(a_g)$ since, although the ecolabel is a more profitable option than unilateral commitment, the ecolabel does not attract new membership.

Sensitivity and bifurcation analysis

As has been shown, the model admits a wide variety of scenarios in terms of number and stability of equilibria. A sensitivity analysis is therefore necessary to determine how the dynamic behavior of the system depends upon the value of critical parameters of the model. Specifically, we focus on two parameters relevant for institutional design and policy implications, namely a_l and a_g. a_l is an important component of the design of the ecolabel, and a_g, as explained below in section 4.3, can be considered to be dependent on the stringency of environmental regulation[23]. It turns out that several local bifurcation values of both parameters can be identified that imply dramatic changes in the characteristics of the set of equilibria (Gandolfo, 1996:pp.469-502; Lorenz, 1989).

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[21] Notice that this is not an optimal control problem so there is no transversality condition to constrain the choice of the initial point and, therefore, nothing guarantees that the system will be placed in the stable arm that leads to equilibrium *c*.

[22] Natural capital is endogenized in section 3.

[23] A more policy-oriented bifurcation analysis is carried out in the model with endogenous *K*.

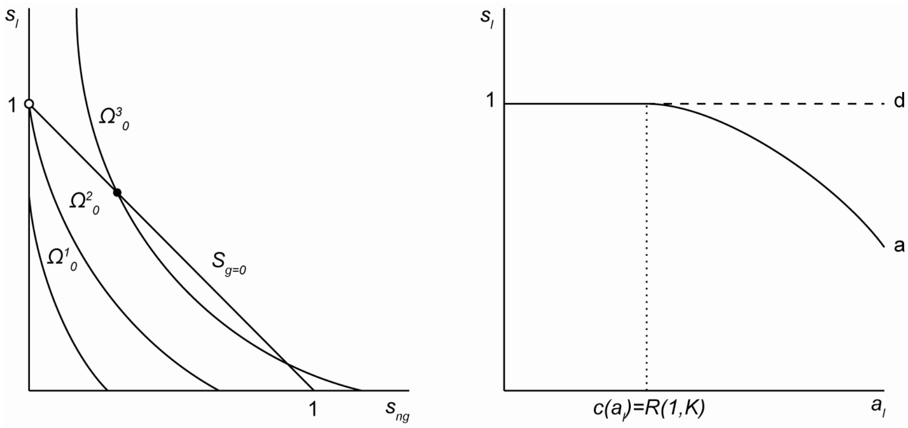

Fig. 8. Sensitivity analysis of the population to a_l. Bifurcation in equilibrium *d*.

Let us first consider the consequences of variations in the abatement levels required to join the ecolabel, a_l[24]. We start from a situation in which a_l is low enough to make the homogeneous all-ecolabel equilibrium *d* stable, as represented in figure 6.a. As shown in figure 8, increases in $c(a_l)$ shift the curve Ω_0 to the right, increasing the intersection point with the vertical axis (where $R(s_l,K)=c(a_l)$), until curve Ω_0 crosses the vertical axis precisely at $s_l=1$, which occurs for $c(a_l)=R(1,K)$. This is a bifurcation value of the parameter since for that $c(a_l)$ the equilibrium *d* becomes non-hyperbolic[25]. For larger values of the parameter, equilibrium *d* becomes unstable and a new stable equilibrium, *a*, emerges[26]. Therefore, a transcritical bifurcation occurs, i.e., a new equilibrium emerges that takes the stability properties of the equilibrium that was first in place, which loses its stability (Gandolfo, 1996pp.473-475). The result is that the long run behavior of the population moves from one stable equilibrium in which all firms join the ecolabel to a new equilibrium in which only a proportion of firms join the certification scheme.

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[24] This analysis can be directly extended to changes in any other cost related to ecolabel membership.

[25] That is to say, as shown in appendix II, for this parameter value, the determinant of the Jacobian becomes zero.

[26] We will assume that $\partial(s_{ng},K)<c(a_g)$ when evaluated in *d* and *a* is satisfied throughout the bifurcation analysis unless otherwise stated.

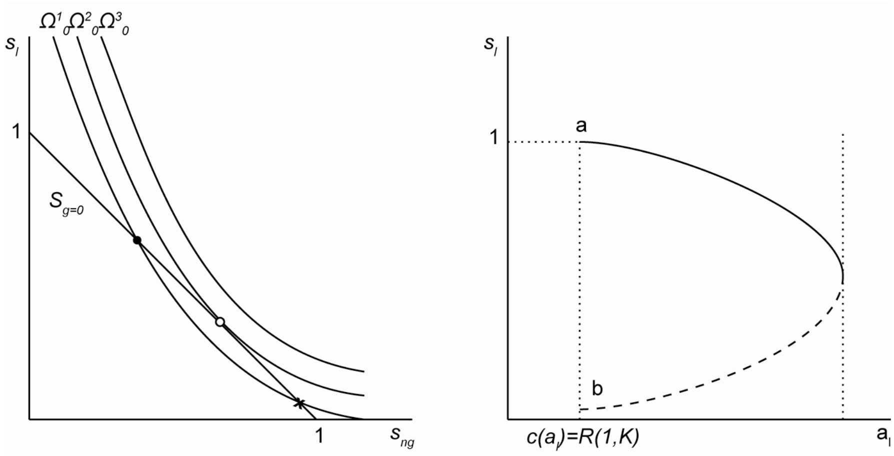

Fig. 9. Sensitivity analysis of the population to a_l. Bifurcation in equilibrium *a*.

A more habitual concern in ecolabelling than full adherence of firms is to achieve a positive proportion of adhered firms in the long run (Font, 2002; WTO, 2002). Figure 9 starts from the endpoint in figure 8, where *a* is a stable equilibrium and *b* is an unstable one. Both *a* and *b* are populations composed of ecolabel and non-green firms. As abatement requirements by the ecolabel further increase, curve Ω_0 shifts to the right until it becomes tangent to $S_{g=0}$. At this tangency point, equilibria *a* and *b* collapse and become a unique non-hyperbolic equilibrium. The bifurcation value of a_l satisfies $c(a_l) = \delta[(1-s_l),K] + R(s_l,K)$ and $-\frac{\partial\delta[(1-s_l),K]}{\partial s_l} = \frac{\partial R(s_l,K)}{\partial s_l}$. For larger values of the parameter a_l, there is no equilibrium with ecolabel and non-green firms, and therefore, the ecolabel cannot prosper. This then constitutes a saddle-node or fold bifurcation (Gandolfo, 1996pp.472-473).

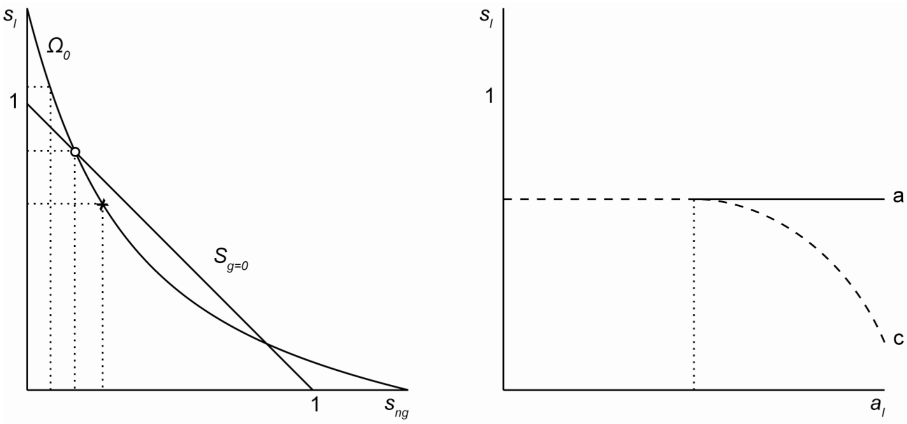

Fig. 10. Sensitivity analysis of the population to a_g.

A third bifurcation analysis, represented in figure 10, involves parameter a_g. Let us consider an initial situation, qualitatively identical to figure 6.b, where a_g is relatively low. In this situation, both equilibria with only ecolabel and non-green firms (equilibria *a* and *b*) are unstable, and the equilibrium where the three strategies coexist (equilibrium *c*) is out of the feasible region. As abatement costs required for obtaining the differentiation premium increase, point *c* moves along Ω_0 to the right. As a result, this point might eventually coincide with equilibrium *a* and become non-hyperbolic. The bifurcation value of a_g satisfies $c(a_g) = \delta[(1-s_l),K]$, $\delta[(1-s_l),K] = c(a_l) - R(s_l,K)$, and $-\frac{\partial\delta[(1-s_l),K]}{\partial s_l} > \frac{\partial R(s_l,K)}{\partial s_l}$. Increases in a_g above this point move equilibrium *c* inside the boundaries of the feasible region and equilibrium *a* becomes stable. Ecolabelling becomes a feasible option. This is, again, a transcritical bifurcation, as described in the first case, with the only difference being that here the existing equilibrium changes from unstable to stable.

4.2. Resource dynamics

We now analyze the dynamic behavior of natural capital for an exogenous composition of the population. The steady state condition, $D(s_{ng},s_l)=F(K)$, defines a relationship between the composition of the population and the stock of natural capital represented by isoclines $\breve{K}(s_{ng},s_l)$ and $\hat{K}(s_{ng},s_l)$ in figure 11.

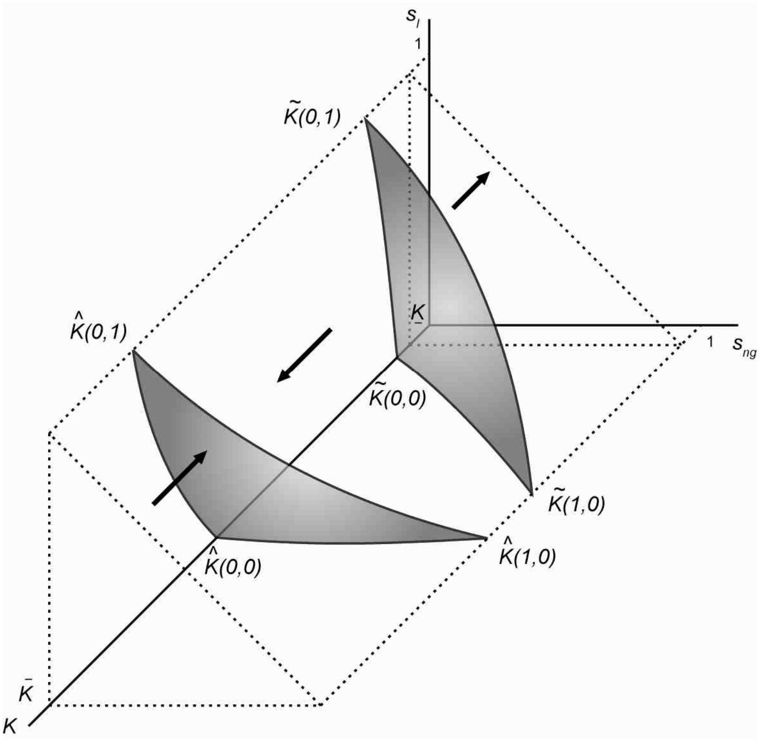

Fig. 11. Resource dynamics of the ecolabel and unilateral commitment model.

The shape of the bi-dimensional spaces $\tilde{K}(\cdot)$and $\hat{K}(\cdot)$ responds to the assumption that $a_l>a_g>a_{ng}$ presented in section 4.1. The edges of the isoclines represent steady state values of the resource for different combinations of two out of the three possible strategies. For instance, the edges in the plane (s_{ng},K) are equivalent to the steady state relationships represented in figure 3, where only green and non-green strategies are considered. The edges at the plane (s_l,K) could be obtained with a figure similar to 3, but considering green and ecolabel strategies, and the edge belonging to the sloping plane of the prism defining the feasible region could be obtained in a similar way, but considering non-green and ecolabel strategies. Points within the interior of the region of the feasible space represent natural capital steady state values when the composition of the population comprises the three strategies.

The dynamics for an exogenous population are simple. For high (above $\hat{K}(\cdot)$) and low (below $\tilde{K}(\cdot)$) values of K, natural capital is decreasing, whereas it is increasing for intermediate values of K (between $\hat{K}(\cdot)$ and $\tilde{K}(\cdot)$). Therefore:

Lemma 6: $\widetilde{K}(s_{ng}, s_l)$ *and* $\hat{K}(s_{ng}, s_l)$ *represent equilibrium spaces of the resource dynamics.* $\widetilde{K}(s_{ng}, s_l)$ *represent unstable equibliria while* $\hat{K}(s_{ng}, s_l)$ *determine asymptotically locally stable equilibria.*

4.3. Dynamics of the combined system

In this section, both natural capital and the composition of the population are endogenous. The model is composed of the three-dimensional system defined by the system of equations 8 and the steady state condition $D(s_{ng},s_l)=F(K)$. Again, let us first explore the steady states of the combined system and later explore the sensitivity of the model to the values of the parameters and bifurcations.

Figure 12 presents a situation where all possible equilibria exist. This figure represents the isoclines of the natural capital $\hat{K}(\cdot)$ and $\widetilde{K}(\cdot)$ and certain isoclines of the population, namely $\widehat{S}_I, \widehat{S}_{II}$ and $\widehat{S}_{III}$. $\widehat{S}_I$, comprise the representation in the plane (s_{ng},K) of the isocline of green and non-green firms first presented in figure 2. $\widehat{S}_{II}$ is an isocline of the label and non-green firms population that is contained in the sloping plane of the prism defining the feasible region. Thus, it is composed of points where there are not green firms and where $\pi_l=\pi_{ng}$. For certain values of *K,* there are a pair of points of $\widehat{S}_{II}$ corresponding to the heterogeneous equilibria *a* and *b* in the model with exogenous capital presented in figures 5 and 6. Finally, when we allow for endogenous natural capital, equilibrium *c* in figures 5 and 6 becomes a line that constitutes the isocline of the population $\widehat{S}_{III}$ where the three strategies coexist.

Other configurations of equilibria are also possible, as shown in figure 13 (equivalent to figure 6 with exogenous *K*) and stated in propositions 3-6, that formally present existence and stability conditions (proofs can be found in appendix III).

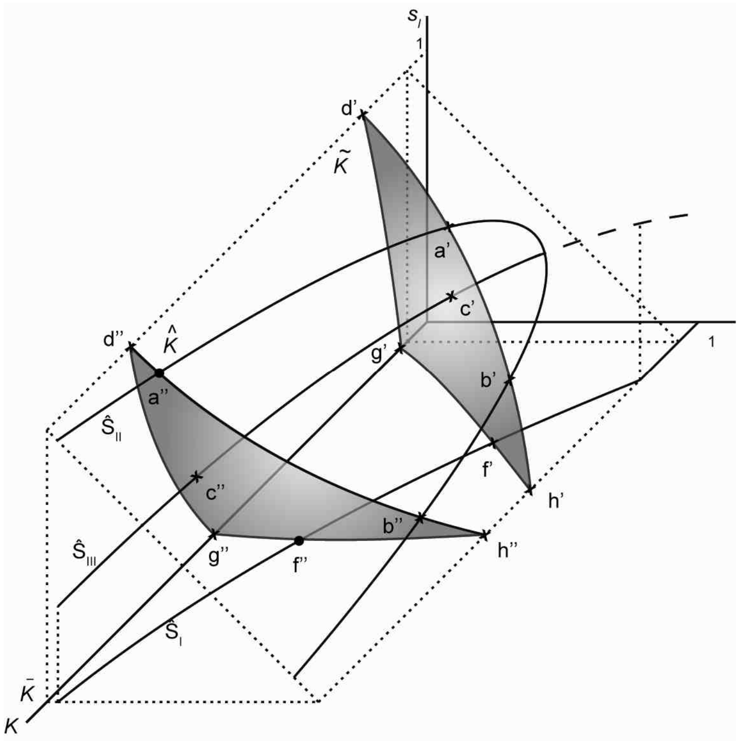

Fig. 12. Equilibrium configuration of the combined system in the ecolabel and unilateral commitment model.

First, given that homogeneous equilibria of the population constitute corner solutions of the system, existence conditions for these equilibria are identical to those of the model with exogenous *K* presented in lemma 3, whereas stability conditions are similar.

Proposition 4: *If a homogeneous equilibrium exists in the model with exogenous capital, it also exists in the combined system. The conditions for asymptotic local stability are those of the model with exogenous K plus F’(K)<0.*

Considering natural capital as an endogenous variable determines that stable homogenous equilibria only exist for the corner values of $\hat{K}(\cdot)$. Figures 13.a and d represent respectively the most optimistic and pessimistic cases in terms of the success of voluntary environmental initiatives. In 13.a the whole population is made up of members of an ecolabel, whereas in 13.d none of the firms engages in any voluntary environmental initiative.

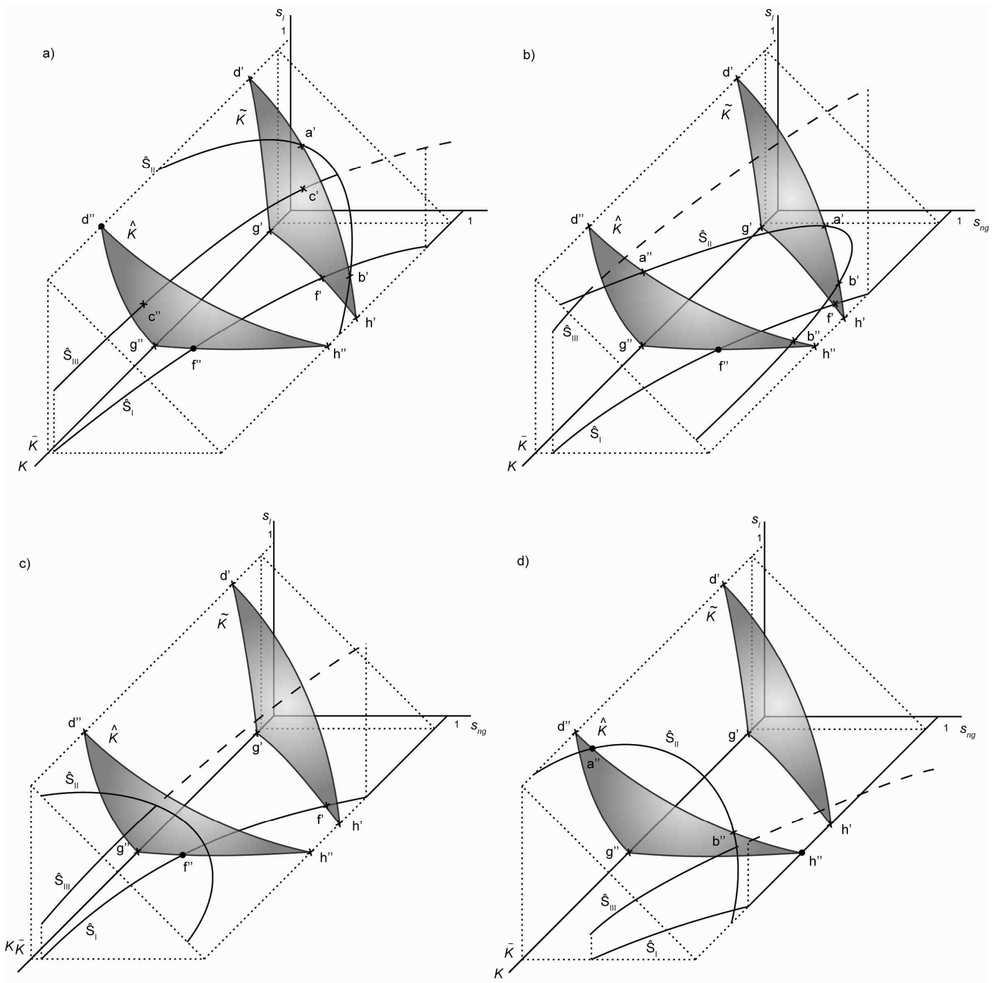

Fig. 13. Other equilibrium configurations of the combined system in the ecolabel and unilateral commitment model.

Moving to heterogeneous equilibria of the combined system, proposition 5 presents the existence conditions, and propositions 5 and 6 present, respectively, the stability conditions for heterogeneous equilibria where two and three strategies coexist.

Proposition 5: *Whenever there exists a set of values of (s_{ng} , s_l , K) belonging to the feasible region such that one of the isoclines of the population shares at least one point with any of the isoclines of the natural capital, a mixed equilibrium of the combined system exists.*

Given that there are two isoclines of the natural resource, this causes the total number of possible heterogeneous equilibria to double with respect to those in the model with exogenous capital. However, stability conditions restrict the number of stable equilibria of the system.

Proposition 6: *A population composed of green and non-green firms is locally asymptotically stable if $F'(K)<0$, and* $\frac{\partial\delta(s_{ng},K)}{\partial s_{ng}}+\frac{N\cdot a_g}{F'(K)}\frac{\partial\delta(s_{ng},K)}{\partial K}>0$. *A population composed of ecolabel and green firms is always unstable. A population composed of ecolabel and non-green firms it is locally asymptotically stable if $F'(K)<0$,* $\delta(s_{ng},K)<c(a_g)$, $\frac{\partial R(s_l,K)}{\partial s_l}<\frac{\partial\delta(s_{ng},K)}{\partial s_{ng}}$, *and* $\left(\frac{\partial\delta(s_{ng},K)}{\partial s_{ng}}-\frac{\partial R(s_l,K)}{\partial s_l}\right)+\frac{N\cdot a_l}{F'(K)}\left(\frac{\partial\delta(s_{ng},K)}{\partial K}+\frac{\partial R(s_l,K)}{\partial K}\right)>0$.

Proposition 6 determines that only those equilibria that belong to $\hat{K}(\cdot)$ can be stable. In addition, it states that, for those equilibria to be stable, a change in the composition of the population must be detrimental for the payoff of the strategy that increases adherence as compared with the other existing strategy in the equilibrium, that is, $\partial(\pi_g-\pi_{ng})/\partial s_{ng}>0$ in the green and non-green equilibrium and $\partial(\pi_l-\pi_{ng})/\partial s_{ng}>0$ in the ecolabel and non-green equilibrium.

Points *f''* in figures 13.a-c represent stable green and non-green equilibria. In figures 13.b and c, this is the only stable equilibrium. In the first case, equilibria containing a positive proportion of ecolabel firms exist, but they are not stable. Specifically, *a''* cannot be stable as in *a''* payoffs of both non-green and ecolabel strategies are lower than those of the green strategy, that is, $\delta(s_{ng},K)>c(a_g)$ and $R(s_l,K)<c(a_l)-c(a_g)$. In figure 13.c, no equilibrium exists in which a proportion of firms are members of the ecolabel, since the minimum level of natural capital that is required for being worth becoming a member of the ecolabel is higher than the level of natural capital that the resource can steadily provide.

In figure 12 there exists a stable equilibrium with positive ecolabel membership. This figure presents four equilibria where ecolabel and non-green firms coexist for s_g=0. Among those, only *a''*, for which *K* is the highest, represents a stable equilibrium.

It can be shown that $K_{a''}>K_{f''}$. Therefore, when successful, the ecolabel can trigger an improvement in environmental quality, and this happens even if there is only partial participation. This result is consistent with previous literature defending that even though an industry-wide voluntary approach is not likely to induce full participation, it can still be a viable means of achieving relevant environmental objectives in aggregate terms for that industry (Alberini et al., 2002).

Proposition 7: *An equilibrium of the combined system where all strategies coexist is always conditionally stable.*

In figures 12 and 13, the isocline $\widehat{S}_{III}$ represents situations where payoffs of the three strategies are equal. Its intersection with the isoclines of natural capital determines equilibria *c'* and *c''*. Associated with each one, there may be a stable arm (if there are two positive and one negative eigenvalues) or a set of convergent paths that lie on a two-dimensional manifold (if there are one positive and two negative eigenvalues). The conditional stability characteristics of *c'* and *c''* imply that the system can follow paths that converge to long run situations where the three strategies coexist. It is also interesting to note that one of these situations is characterized by a low level of natural capital, $\breve{K}(\cdot)$. Nevertheless, these equilibria are not locally asymptotically stable, since any marginal deviation from either *c'* or *c''* out of the stable arm or the stable two-dimensional manifold places the system in a divergent path.

Sensitivity and bifurcation analysis of the combined system

When considering the combined system, the possible scenarios in terms of number and stability of equilibria increase with respect to those of the population dynamics. Thus, the values of critical parameters that imply dramatic changes in the equilibrium configuration are larger. In this section, we do not develop a comprehensive sensitivity analysis, but rather present an extension of the sensitivity analysis developed for the population dynamics (we also assume in this section that the relation between $\widehat{S}_{II}$ and $\widehat{S}_{III}$ is such that *a''* and *d''* are stable unless otherwise stated). First, we focus our attention on bifurcations resulting from changes in a_l and a_g which affect the stability of equilibria where a positive proportion of firms join the ecolabel in the long run. Second, we consider changes in the size of the population of users of the natural CPR. Note that now several parameters of the system affect simultaneously the isoclines of the population and the isoclines of the natural resource, making the sensitivity analysis more complex. All proofs and demonstrations are presented in appendix III.

Let us start by considering the consequences of variations in abatement levels required to join the ecolabel, a_l. Again, there is a value of a_l generating a bifurcation point that determines the stability of the homogeneous all-ecolabel population equilibrium (solid line in figure 14). Figure 14 represents the sloping plane of the prism defining the feasible region.

Proposition 8: *If* $c(a_l) = R(1, \hat{K})$, *d'' is a non-hyperbolic equilibrium.*

For lower values of a_l, *d''* is a stable equilibrium of the system, whereas for higher values of a_l, *d''* becomes unstable and a new stable equilibrium *a''* appears.

Since this bifurcation affects a corner-solution equilibrium, the conditions determining the existence of a transcritical bifurcation in equilibrium *d''* are the same as in the model with exogenous capital, restricting it to the equilibrium in $\hat{K}$.

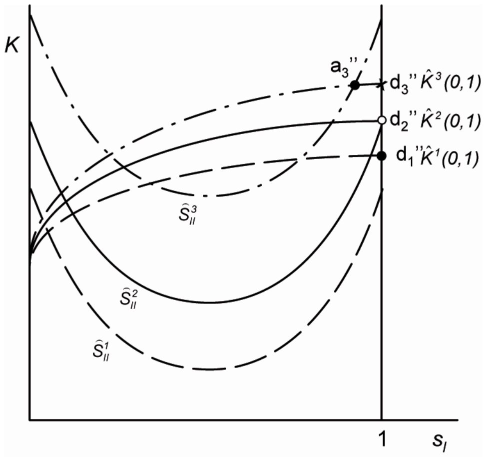

Fig. 14. Sensitivity analysis of the combined system to a_l. Bifurcation in equilibrium *d''*.

Further, as was also occurring in the model with exogenous capital, there exists a value of a_l that determines that the ecolabel can be viable in the long run.

Proposition 9: *Equilibrium a'' is non-hyperbolic if*
$$\left(\frac{\partial\delta(s_{ng},K)}{\partial s_{ng}}-\frac{\partial R(s_l,K)}{\partial s_l}\right)+\frac{N\cdot a_l}{F'(K)}\left(\frac{\partial\delta(s_{ng},K)}{\partial K}+\frac{\partial R(s_l,K)}{\partial K}\right)=0$$ *evaluated in that point.*

If there is a value $a_l \in (0,1)$ such that *a''* exists, then given the assumption $\lim_{a_l\to 1} c(a_l)=\infty$, there is also a value $a_l \in (0,1)$ such that $\hat{S}_{II}$ is tangential to $\hat{K}$[27]. At the tangency point, proposition 9 holds; that is, the marginal effect on the difference of payoffs of changes in the composition of the population between being ecolabel and non-green is zero. This occurs when equilibria *a''* and *b''* converge at the tangential point, becoming a unique, non-hyperbolic equilibrium. For larger values of a_l, there are no equilibria with a positive proportion of ecolabel firms. This constitutes a saddle-node or fold bifurcation (Gandolfo, 1996,pp.472-473).

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[27] If a' exists for a value $a_l \in (0,1)$, then it is also true that there is a value $a_l \in (0,1)$ such that $\hat{S}_{II}$ is tangential to $\tilde{K}$.

Notice that proposition 9 implies that, at the bifurcation, $\partial R/\partial s_l < \partial\delta/\partial s_{ng}$; that is, the sensitivity of reputation premiums to changes in the population composition is lower than that of premiums from green differentiation.

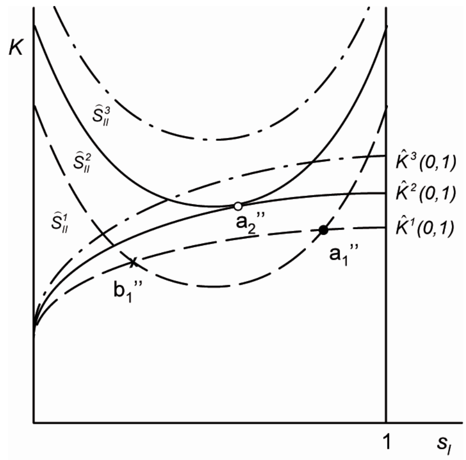

Fig. 15. Sensitivity analysis of the combined system to a_l. Bifurcation in equilibrium *a''*.

These two bifurcation analyses underline the importance of ecolabels' abatement and other costly requirements for the success of these initiatives. Thus, it has been widely reported that a difficulty for the operation of an ecolabel is that too-stringent criteria are set (Buckley, 2002; Mihalic, 2000; WTO, 2002) and that the administrative fees required to enter the program might deter adherence (Sasidharan et al., 2002; WTO, 2002). Among others, one criticism of tourism ecolabels is that they are expensive in terms of both money and time (Font, 2002). In developing countries, it has been defended that ecolabelling programs would be pressured into lowering their criteria to increase industry participation (Sasidharan et al., 2002). Additionally, it is proposed that costs of membership in an ecolabel should be restricted to cover only part of the administrative costs (WTO, 2002).

Note that the location of the bifurcation differentiating between situations where the ecolabel can or can not survive in the long run depends not only on the costs associated with ecolabel membership, but also on factors affecting the reputation function. Then, the comments in section 2 regarding the crucial importance of marketing campaigns related to the ecolabel and on building credibility for the information released become relevant here. In addition to these, a recent phenomenon to be considered is the over-launch of green certification programs in tourism, which is alleged to confuse costumers. There is a concern that the presence of a wide array of ecolabels and the different information released by such schemes would prevent visitors from making objective judgments regarding the legitimacy of firms' environmental responsibility claims, lowering the value of all initiatives (Ayuso, 2007; Lübbert, 2001; Mihalic, 2000; Sasidharan et al., 2002). Further, false or misleading labeling could lead to an adverse selection situation where consumers could not detect the environmental attributes of the product before purchase though that information would be available to sellers (Ibanez et al., 2008). According to Ibanez and Grolleau (2008), under this condition, if labeling costs for polluting firms are very low, low-polluting firms will not be able to distinguish themselves and will be driven out of the market. Only if labeling is much more costly for polluting than for low-polluting firms will these two groups voluntarily choose different environmental strategies, with environmentally friendly firms labeling their products.

As in the section with exogenous capital, we can also analyze the implications of a_g in the configuration of equilibria. The initial situation in figure 16 is qualitatively identical to figure 13.b. Given that a_g is relatively low, equilibria a_1'' and b_1'' are unstable, and $\widehat{S}_{III}$ is out of the feasible region for values of K belonging to $\hat{K}(\cdot)$. Increases in a_g do not affect $\widehat{S}_{II}$, but $\widehat{S}_{III}$ and $\hat{K}(\cdot)$ are modified. Strengthening abatement requirements in order to undertake unilateral commitments shifts $\hat{K}(\cdot)$ upwards. Changes of $\widehat{S}_{III}$ are more complex. Increasing a_g entails a right-down movement in figure 13.b, which is represented by a left-shift in figure 16. Accordingly, $\widehat{S}_{III}$ will eventually cross $\widehat{S}_{II}$ in equilibrium a_2'', turning it a non-hyperbolic equilibrium. Further increases in a_g make a_3'' stable, and $\widehat{S}_{III}$ crosses $\hat{K}(\cdot)$, generating a new non-stable equilibrium, c''.

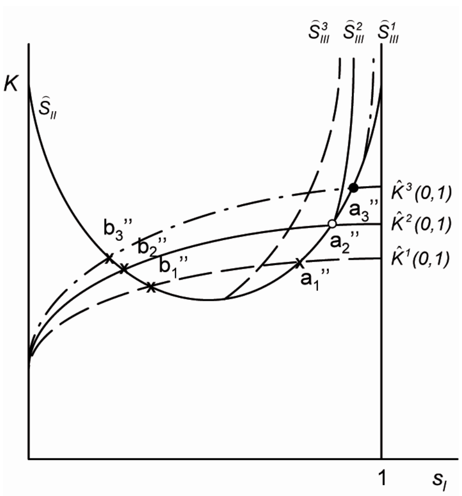

Fig. 16. Sensitivity analysis of the combined system to a_g.

Proposition 10: *Equilibrium a'' is non-hyperbolic if* $\delta(s_{ng}, \hat{K}) = c(a_g)$ *evaluated at that point.*

In other words, proposition 10 states that when *c''* and *a''* collapse, they become a unique, non-hyperbolic equilibrium and a transcritical bifurcation occurs. Given that equilibrium *a''* belongs to $\hat{S}_{II}$, when $\delta(s_{ng}, \hat{K}) = c(a_g)$, then $R(s_l, \hat{K}) = c(a_l) - c(a_g)$. Recall that according to lemma 5 and proposition 4, these are the conditions determining existence of *c''*. Then, abatement costs to undertake unilateral commitments are strictly compensated by premiums to green differentiation, while at the same time extra abatement costs to become a member of an ecolabel (when being green) are strictly compensated by the reputation premium. Higher levels of a_g make $\delta(s_{ng}, \hat{K}) < c(a_g)$, and thus, according to proposition 6, *a''* becomes stable.

The abatement level implemented by green firms is not, in principle, a policy parameter, as it is (exogenously) chosen by individual firms. However, a_g should increase with the stringency of environmental regulation since, in our model, green behavior is justified by the aim of differentiation with respect to firms that just meet legal mandates. Under this interpretation, the previous bifurcation analysis implies that success of ecolabels may be favored by more stringent regulation. This seems to support a crowding-in effect of environmental regulation on voluntary environmental certification. This is consistent with claims by the manufacturing literature that voluntary activity is a complement to regulation (Lyon et al., 2002). Empirical estimates show that public policy can create the regulatory and market-based pressures that induce adoption of environmental management systems by means of stringent mandatory regulation and the provision of environmental information about firms to the public (Anton et al., 2004). This evidence is consistent with analytical findings that support the idea that firms are more likely to join a voluntary program the stricter the program's regulatory background (Segerson et al., 1998; Vidreras et al., 2000). The limited research to date for tourism in this area conforms to these findings. Empirical examinations in Costa Rica support the notion that, in addition to market incentives, adequate institutional pressures may also be necessary conditions for adherence to environmental management systems by hotels in order to promote compliance beyond regulated environmental behavior (Rivera, 2004). The idea that tourism ecolabels should be integrated with public policy mechanisms such as environmental regulations and standards to be most effective has been defended (Buckley, 2002).

Another parameter of the game that has profound implications in the configuration of equilibria is the size of the population of firms that make use of the CPR. Increases in *n* shift the isoclines of the natural resource as shown in figure 17.

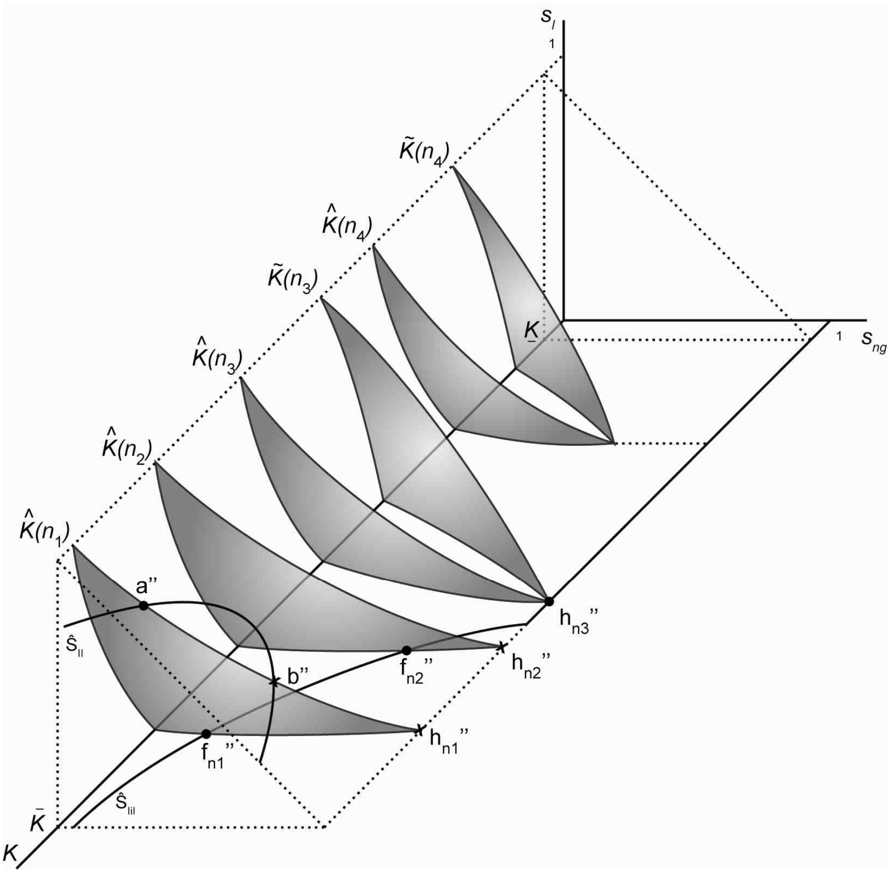

Fig. 17. Sensitivity of the combined system to *n*.

The result is that the degree of implementation of voluntary initiatives is affected by the size of the population. It is possible that starting from an initial situation where the long-term population configuration can contain a positive proportion of ecolabel firms ($a^{"}_{n_1}$), increases in the population erode the economic incentives to be a member of the ecolabel. Then, unilateral commitments are the only voluntary initiative that might be undertaken by this higher population of tourism firms ($f^{"}_{n_2}$). If the population of firms increases further, it can be the case that even the incentives to be green are undermined and no firm in the population develops voluntary environmental initiatives ($h^{"}_{n_3}$). Given an all-non-green population composition, it is obvious that further increases in the population will eventually lead to the exhaustion of the resource (as is the case for n_4 in figure 17).

However, depending on the fragility of the natural resource, it is possible that exhaustion may appear even with a positive proportion of firms engaging in voluntary initiatives. Figure 18 presents a situation where extinction of the resource is possible for values of s_g>0.

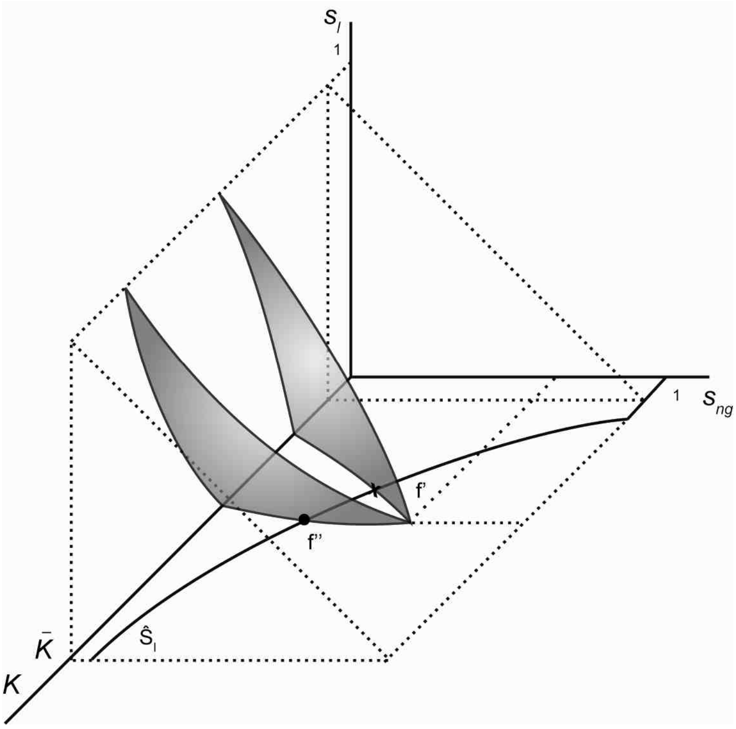

Fig. 18. Extinction of the CPR for s_g>0.

Therefore, the existence of economic incentives to undertake voluntary environmental initiatives can not preclude tragic results when we allow increases in the number of CPR users. Consequently, it is necessary to limit the number of tourism firms that can make use of a natural CPR, even though these engage in voluntary initiatives that reduce their individual impacts. If there is no restriction on the number of firms that can use a particular CPR, this can entail initially ecolabelled or green firms giving up their abatement strategies and abandoning the green niche. This could eventually lead to pressures on the resource above its regeneration capacity and thus, the CPR would collapse.

5. Conclusion

This chapter analyzes changes in the economic incentives of tourism firms to undertake voluntary environmental initiatives after an ecolabel is exogenously created in a setting in which there was scope for the existence of unilateral commitments. We develop an evolutionary game-theoretical model of a population of tourism firms making use of a natural CPR, the environmental quality of which is endogenously considered.

First, we consider a situation in which available strategies to tourism firms are compliance with environmental regulations or the undertaking of voluntary unilateral commitments to improve their environmental behavior beyond that legally mandated. Second, we extend the unilateral commitment model by introducing an ecolabel. This is a non-coercive institutional change based on voluntary adherence by tourism firms. We do not explicitly model the creation of the ecolabel, but analyze the dynamic behavior of the system once the ecolabel is exogenously introduced. According to some empirical evidence, we assume that abatement efforts required to become a member of the ecolabel are higher than those to undertake unilateral commitments. Thus, this strategy entails higher costs of joining.

Therefore, we model two different types of voluntary initiatives and the strategy of no voluntary abatement. The literature on voluntary action has compared one type of voluntary initiative (that being either unilateral commitments, negotiated agreements or ecolabels) with the no voluntary abatement option, but to the best of our knowledge, no study has simultaneously analyzed different voluntary initiatives vs. the no-action situation. Thus, we extend the literature in this direction.

We show that individual voluntary initiatives in the form of unilateral commitments can emerge even without the existence of informal rewards or punishment, as opposed to previous results in the related literature (Osés et al., 2007; Sethi et al., 1996). In our model, incentives to follow environmentally-friendly strategies depend on profit-seeking motivations raised by demand effects. As in Osés and Viladrich, and contradictory to Sethi and Somanathan (1996), heterogeneous populations composed of green and non-green firms can exist in the long run. For this to occur, it is necessary that for a positive proportion of green firms, premiums from green differentiation equal abatement costs of unilateral commitments. The proportion of green firms in the long run further depends on the steady-state level of natural capital: the higher the natural capital, the larger the green niche the industry can develop. Thus, like Osés and Viladrich (2007) our model reproduces real-world situations, where heterogeneity of agents is obvious to empirical researchers (Marshall, 2005; Ostrom, 2000; Ostrom, Burger, Field, Norgaard, & Policansky, 1999) and contributes to the theoretical work to explain these realities.

Once the institutional setting is expanded to include an ecolabel, the population can evolve towards a second heterogeneous composition with ecolabel and non-green firms. When the ecolabel prospers, green firms tend to disappear. Beyond a certain population composition, it is more profitable for green firms to develop further abatement and become members of the ecolabel. Equilibria with the three strategies can exist but cannot be stable. It is noteworthy that when an ecolabel prospers, the proportion of non-green firms is lower and the steady-state natural capital of the CPR is higher than that resulting from populations with firms undertaking unilateral commitments.

Several factors affect the long-term subsistence of the ecolabel, namely the institutional setting, the initial proportion of promoters of the ecolabel, the type of firms that act as promoters, the extent to which unilateral commitments are undertaken, and the environmental quality of the CPR.

The institutional setting of environmental regulation and voluntary environmental initiatives strongly influences the capacity of an ecolabel to exist in the long run. These factors jointly determine the abatement costs of voluntary initiatives, which is one of the crucial factors that determine the existence and stability of populations with ecolabel firms. In addition, for an ecolabel to exist in the long run, it is necessary that a minimum contributing set of firms join initially so that a critical reputation premium is created. The initial reputation premium has to at least compensate for the extra abatement cots of becoming a member of the ecolabel for green firms. This result shows a fundamental difference between the two voluntary initiatives since unilateral commitments can be initiated by a single firm, whereas some coordinated action among tourism stakeholders is required to organize an initial group of promoters. In addition, the type of firms that act as promoters is also relevant. When only green firms act as promoters of the ecolabel, the proportion of initial promoters required for the long-term survival of the ecolabel is lower than when non-green firms also initially join. Adherence by non-green firms reduces premiums from green differentiation, making the two environmentally-friendly strategies less attractive. Further, the long-term survival of the ecolabel depends on the extent to which unilateral commitments are undertaken by the population of firms. If the ecolabel is introduced too early along the path of implementation of unilateral commitments, the ecolabel can erode the environmentally-friendly path by inducing green firms to join an ecolabel that cannot gather enough members to subsist in the long run. Finally, as for unilateral commitments, it is required that a minimum level of natural capital be obtained for the ecolabel to prosper. Once this has occurred, there is a feed-back effect between growth in the proportion of ecolabel firms and natural capital. The higher the proportion of ecolabels, the higher the level of natural capital, and this in turn enhances the incentives to become a member of the ecolabel.

Further, we also provide an explanation for situations in which voluntary initiatives are generally adopted or do not emerge at all. When demand effects are too low, environmental quality of the CPR is not high enough, impediments exist to coordination, or firms do not consider voluntary initiatives as a relevant strategy to consider, homogeneous populations where no firm undertakes voluntary abatements will result. This conforms to findings from empirical examinations by Ostrom (1990) on design principles missing in systems failing to self-govern (table

2.2). Further, we show that it is also possible that an ecolabel can raise its numbers of adherents until all firms adhere to the certification. This would be consistent with evidence in the manufacturing literature where standards of ecolabels lose their connotations of a label and are perceived as a requirement by consumers (Buckley, 2002). Contrary to ecolabels, which increase their attractiveness as more firms join, we show that individual voluntary initiatives based on differentiation for green niches can not extend to the whole population. When all firms are green, there is no differentiation, and thus firms will prefer to avoid abatement costs.

There are several natural extensions that can be developed from the model presented in this chapter. First, we could endogenously model demand for green attributes of firms and the CPR by tourism markets, following the literature in this respect on industrial economics. A second alternative to include demand markets would be to consider the role of tour operators as intermediaries that might have green preferences (Calveras et al., 2005 being an example). Second, we could explicitly model the role of regulation by governmental agencies in the model. As already mentioned, the baseline level of mandated abatement influences abatement costs to improve environmental behavior beyond regulation, which affects the existence and stability of heterogeneous populations of firms. Third, in addition to the diffusion mechanism of strategies (which we have modeled by means of replicator dynamics), we could introduce a network of social interaction to the system. This could determine that interactions do not occur globally in the population, but that there are criteria of preferable interaction (e.g., with close neighbors). Finally, we could analyze the effect on price premiums of competition between destinations for an international green niche of tourists. Consequently, differentiation premiums might not totally disappear when all firms using a particular CPR are green. Firms would then cooperate to attract tourists to the destination and later compete at the destination level, as noted in the concept of competition in the tourism literature (Edgell & Haenisch, 1995).

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Appendix I: Unilateral commitment model

A steady state of a two-dimensional system is locally asymptotically stable when the determinant of the Jacobian evaluated at that point has a positive value while the trace is negative. It is locally asymptotically unstable when both the determinant and the trace are positive, whereas it is a saddle-point when the determinant is negative.
This model is comprised of equations 4 and 5. Linearization of these equations results in a system whose Jacobian is:

$$J = \begin{pmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{pmatrix}$$

where
$$\begin{aligned} J_{11} &= F'(K) \\ J_{12} &= -N \cdot a_g \\ J_{21} &= -s_{ng}(1-s_{ng})\sigma \\ J_{22} &= -\alpha + 2s_{ng}\alpha - s_{ng}(1-s_{ng})\lambda \end{aligned}$$

where we have defined
$$\begin{aligned} \alpha &= \delta(s_{ng}, K) - c(a_g) \\ \lambda &= \frac{\partial \delta(\cdot)}{\partial s_{ng}} \\ \sigma &= \frac{\partial \delta(\cdot)}{\partial K} \end{aligned}$$

and K and s_{ng} take different values depending on the specific steady state we consider.

Proof of proposition 1

In a heterogeneous equilibrium, according to lemma 1, α=0 and consequently,

$$|J| = F'(K)\left[-s_{ng}(1-s_{ng})\lambda\right] - N \cdot a_g s_{ng}(1-s_{ng})\sigma$$

$$\text{trace}J = F'(K) - s_{ng}(1-s_{ng})\lambda$$

For this equilibrium to be locally asymptotically stable it is necessary that $F'(K)<0$ and $\lambda + \frac{N \cdot a_g}{F'(K)}\sigma > 0$. $F'(K)<0$ is necessary for the determinant not being negative, and given that $F'(K)<0$, condition $\lambda + \frac{N \cdot a_g}{F'(K)}\sigma > 0$ guarantees that it is positive. $F'(K)<0$ also makes the trace negative.

Proof of proposition 2

In a homogeneous all-non-green equilibrium, s_{ng}=1. Thus,

$$|J| = F'(K)\alpha$$

$$\text{trace}J = F'(K)$$

For the trace to be negative it is necessary that $F'(K)<0$. Given that $F'(K)<0$, it is necessary that $\alpha<0$ for the determinant to be positive.

Appendix II: Ecolabel and unilateral commitment model with exogenous K

This is again a two-dimensional system and, therefore, the rules for stability are those stated in appendix I. The equations of this model are those of expression 8. Linearization results in a system whose Jacobian is:

$$J = \begin{pmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{pmatrix}$$

where
$$\begin{aligned} J_{11} &= -(1-s_{ng})\alpha - s_l\beta + s_{ng}\alpha - s_{ng}(1-s_{ng})\lambda \\ J_{12} &= -s_{ng}\beta - s_{ng}s_l\varepsilon \\ J_{21} &= s_l\alpha + s_l s_{ng}\lambda \\ J_{22} &= (1-s_l)\beta + s_{ng}\alpha - s_l\beta + s_l\beta + s_l(1-s_l)\varepsilon \end{aligned}$$

and where we have additionally defined
$$\begin{aligned} \beta &= R(s_l, K) - [c(a_l) - c(a_g)] \\ \varepsilon &= \frac{\partial R(\cdot)}{\partial s_l} \\ \Omega &= \delta(s_{ng}, K) + R(s_l, K) - c(a_l) \end{aligned}$$

where K is exogenous and s_{ng} and s_l take the different steady state values.

Proof of Lemma 3

The stability of homogeneous equilibria of the population can be proven by:

Homogeneous all-ecolabel equilibrium (s_l=1),

$$|J| = \beta\Omega$$

$$\text{trace}J = -(\beta + \Omega)$$

Then, for this equilibrium to be locally asymptotically stable, it is required that $R(1,K)>c(a_l)$, since consequently β>0 and Ω>0, and thus the determinant is positive and the trace negative.

Homogeneous all-green equilibrium (s_{ng}=0; s_l=0),

$$|J| = -\alpha\beta$$

$$\text{trace}J = \beta - \alpha$$

For this equilibrium to be stable, it is required that α>0 for s_{ng}=0, or equivalently, that $\delta(0,K)-c(a_g)=-c(a_g)>0$. This is an impossible condition to meet, given that we have assumed $c(a_g)\geq 0$.

Homogeneous all-non-green equilibrium (s_{ng}=1),

$$|J| = \alpha\Omega$$

$$\text{trace}J = \alpha + \Omega\,.$$

For this equilibrium to be stable, it is necessary that $\delta(1,K)<c(a_g)$, which makes α<0 and Ω<0.

Proof of Lemma 4

Here we analyze the stability of heterogeneous equilibria where only two strategies exist.

Heterogeneous equilibria of the population composed of non-green and green firms (s_{ng},0), for $s_{ng} \in (0,1)$,

$$|J| = -s_{ng}(1 - s_{ng})\lambda\beta$$

$$\text{trace}J = \beta - s_{ng}(1 - s_{ng})\lambda$$

$$\text{Discriminant}J = \left[\beta + s_{ng}\left(1 - s_{ng}\right)\lambda\right]^2$$

For this equilibrium to be stable, it is necessary that β<0, which is a condition that always holds given that we have assumed $c(a_g)<c(a_l)$. Moreover, the discriminant is positive, and thus convergence to this equilibrium is always monotonic.

Heterogeneous equilibria of the population composed of ecolabel and green firms $(0,s_l)$ for $s_l \in (0,1)$,

$$|J| = -s_l(1-s_l)\varepsilon\alpha$$

$$\text{trace}J = -\alpha + s_l(1-s_l)\varepsilon$$

There is no possible combination of parameter values that makes the determinant positive and the trace negative simultaneously in this equilibrium. Thus, it is always unstable.

Heterogeneous equilibria of the population composed of ecolabel and non-green firms (s_{ng},s_l), for $(s_{ng}+s_l)=1$,

$$|J| = s_l(1-s_l)\alpha(\varepsilon-\lambda)$$

$$\text{trace}J = \alpha + s_l(1-s_l)(\varepsilon-\lambda)$$

$$\text{Discriminant}J = [\alpha - s_l(1-s_l)(\varepsilon-\lambda)]^2$$

For this equilibrium to be stable, it is necessary that $\alpha<0$ and $\varepsilon<\lambda$. Since the discriminant is positive, convergence to this equilibrium is monotonic.

Proof of Lemma 5

Heterogeneous equilibria where the population is composed of ecolabel, green and non-green firms (s_{ng},s_l), for $(s_{ng}+s_l) \in (0,1)$,

$$|J| = -\lambda\varepsilon s_{ng}s_l(1-s_l-s_{ng})$$

This determinant is negative for any possible combination of the parameter values, and thus, this equilibrium is a saddle-point.

Appendix III: Ecolabel and unilateral commitment model with endogenous K

The characteristic equation of the Jacobian of a three-dimensional system is:

$$x^3 - c_1x^2 + c_2x - c_3 = 0$$

where:

$c_1=TraceJ$

c_2=sum of all second-order principal minors of J

$c_3=|J|$

According to Descartes' theorem, the number of positive roots of the characteristic equation cannot exceed the number of changes in the sign of the coefficients, whereas the number of positive roots cannot be greater than the number of continuations in the signs of the coefficients (Gandolfo, 1996, p.54). This implies, on the one hand, that there are three negative roots if and only if *traceJ*<0, c_2>0 and $|J|$<0. In this case the steady state is stable. On the other hand, there are three positive roots if and only if *traceJ*>0, c_2>0 and $|J|$>0 in this second case, and the steady state is unstable. The other possibilities give involve a combination of positive and negative roots that result in a conditionally stable equilibrium, that is, there is a stable manifold or stable arm associated with that equilibrium.

When natural capital is endogenous, the system is defined by expressions 8 and 9. Linearization results in a system whose Jacobian is:

$$J = \begin{pmatrix} J_{11} & J_{12} & J_{13} \\ J_{21} & J_{22} & J_{23} \\ J_{31} & J_{32} & J_{33} \end{pmatrix}$$

where

$$\begin{aligned}
J_{11} &= F'(K) \\
J_{12} &= -N \cdot a_g \\
J_{13} &= N(a_l - a_g) \\
J_{21} &= -s_{ng}(1-s_{ng})\sigma - s_{ng}s_l\theta \\
J_{22} &= -(1-s_{ng})\alpha - s_l\beta + s_{ng}\alpha - s_{ng}(1-s_{ng})\lambda \\
J_{23} &= -s_{ng}\beta - s_{ng}s_l\varepsilon \\
J_{31} &= s_l(1-s_l)\theta + s_l s_{ng}\sigma \\
J_{32} &= s_l\alpha + s_l s_{ng}\lambda \\
J_{33} &= (1-s_l)\beta + s_{ng}\alpha - s_l\beta + s_l(1-s_l)\varepsilon
\end{aligned}$$

and where additionally we have defined $\theta = \dfrac{\partial R}{\partial K}$

K, s_l and s_{ng} take different values depending on the specific steady state we consider.

Proof of proposition 4

Homogeneous all-ecolabel equilibrium (s_l=1),

$$|J| = F'(K)\beta\Omega$$
$$\text{trace}J = F'(K) - \beta - \Omega$$
$$c_2 = -F'(K)\Omega - F'(K)\beta + \beta\Omega$$

The determinant and trace are negative and c_2 positive if and only if $F'(K)<0$, $\beta>0$, and $\Omega>0$ in the steady state. This is guaranteed for $F'(K)<0$ and $R(1,K)>c(a_l)$. For any other combination, either the determinant is positive, or a positive c_2 and a negative trace cannot coexist.

Homogeneous all-green equilibrium (s_l=0; s_{ng}=0),

$$|J| = -F'(K)\alpha\beta$$
$$\text{trace}J = F'(K) + \beta - \alpha$$
$$c_2 = F'(K)\beta - F'(K)\alpha - \beta\alpha$$

This equilibrium could be stable if $F'(K)<0$, $\alpha>0$, and $\beta<0$. For any other combination, either the determinant is positive, or a positive c_2 and a negative trace cannot coexist. However, it is impossible that $\alpha>0$ for s_{ng}=0, given that we have assumed $c(a_g)\geq 0$. Thus, homogeneous all-green equilibria are always unstable.

Homogeneous all-non-green equilibrium (s_{ng}=1),

$$|J| = F'(K)\alpha\Omega$$
$$\text{trace}J = F'(K) + \alpha + \Omega$$
$$c_2 = F'(K)\Omega + F'(K)\alpha + \alpha\Omega$$

The determinant and trace are negative and c_2 positive if and only if $F'(K)<0$, $\alpha<0$, and $\Omega<0$ in the steady state. For any other combination, either the determinant is positive, or a positive c_2 and a negative trace cannot coexist.

Proof of proposition 6

Here we analyze the stability of heterogeneous equilibria where only two strategies exist.

Heterogeneous equilibria composed of non-green and green firms

$$|J| = -s_{ng}(1-s_{ng})\beta\left[F'(K)\lambda + N\cdot a_l\sigma\right]$$

$$\text{trace}J = F'(K) - s_{ng}(1-s_{ng})\lambda + \beta$$

$$c_2 = -s_{ng}(1-s_{ng})\frac{|J|}{\beta} + \beta\left[F'(K) - s_{ng}(1-s_{ng})\lambda\right]$$

Given that we have assumed $c(a_l)>c(a_g)$, necessarily $\beta<0$. Given this, if $F'(K)>0$, then the determinant is positive. If $F'(K)<0$, the trace is negative, and a necessary condition for the determinant to be negative is $\lambda + \frac{N\cdot a_g}{F'(K)}\sigma > 0$, which is also sufficient for c_2 to be positive. Therefore, the steady state is stable if and only if $F'(K)<0$, and $\lambda + \frac{N\cdot a_g}{F'(K)}\sigma > 0$.

Heterogeneous equilibria composed of green and ecolabel firms

$$|J| = s_l(1-s_l)\alpha\left[-F'(K)\varepsilon + N(a_l - a_g)\theta\right]$$

$$\text{trace}J = F'(K) + s_l(1-s_l)\varepsilon - \alpha$$

$$c_2 = -s_l(1-s_l)\left[\theta N(a_l - a_g) - \varepsilon F'(K)\right] - \alpha\left[F'(K) - s_l(1-s_l)\varepsilon\right]$$

The assumption $c(a_g)\geq 0$ implies that, in this equilibrium, necessarily $\alpha\leq 0$. Given this, $F'(K)<0$ implies a positive trace, and $F'(K)>0$ implies that a negative trace and positive c_2 cannot coexist. Thus, this equilibrium is always unstable.

Heterogeneous equilibria composed of ecolabel and non-green firms

$$|J| = -s_l(1-s_l)\alpha\left[F'(K)(\lambda-\varepsilon) + N\cdot a_l(\sigma+\theta)\right]$$

$$\text{trace}J = F'(K) + \alpha + s_l(1-s_l)(\varepsilon - \lambda)$$

$$c_2 = \alpha[F'(K) - s_l(1-s_l)(\lambda-\varepsilon)] - s_l(1-s_l)[F'(K)(\lambda-\varepsilon) + N\cdot a_l(\sigma+\theta)]$$

These three conditions are only met simultaneously when $F'(K)<0$, $\alpha<0$, $\varepsilon<\lambda$, and $(\lambda-\varepsilon) + \frac{N\cdot a_l}{F'(K)}(\sigma+\theta) > 0$. For other situations, either the determinant is positive, the trace is positive, a positive c_2 and negative determinant cannot coexist, or, finally, a positive c_2 and negative trace cannot coexist.

Proof of proposition 7

Heterogeneous equilibria where the population is composed of ecolabel, green and non-green firms (s_{ng},s_l), for $(s_{ng}+s_l)\in(0,1)$,

$$|J| = s_{ng}s_l(1-s_{ng}-s_l)\left[-F'(K)\lambda\varepsilon + N(a_l-a_g)\lambda\theta - N\cdot a_g\sigma\varepsilon\right]$$

$$\text{trace}J = F'(K) - s_{ng}(1-s_{ng})\lambda + s_l(1-s_l)\varepsilon$$

$$c_2 = F'(K)[-s_{ng}(1-s_{ng})\lambda + s_l(1-s_l)\varepsilon] - \lambda\varepsilon s_{ng}s_l(1-s_{ng}-s_l) -$$
$$-N(a_l-a_g)[s_l(1-s_l)\theta + s_l s_{ng}\sigma] - N\cdot a_g[s_{ng}(1-s_{ng})\sigma + s_{ng}s_l\theta]$$

For *F'(K)*>0, it is necessary that $s_l(1-s_l)\varepsilon - s_{ng}(1-s_{ng})\lambda<0$ for the trace to be negative, but this determines that c_2 is negative. Therefore, there cannot be three positive roots and *c'* is not stable.
For *F'(K)<0,* it is necessary that $F'(K)\lambda + Na_g\sigma>0$ for the determinant to be negative. This is not compatible with c_2 being positive. Thus, there cannot be three positive roots and *c''* cannot be stable.
For *F'(K)*>0, it is necessary that $F'(K)\varepsilon - N(a_l-a_g)\theta<0$ for the determinant to be positive, and this implies that c_2 is negative. Consequently, there cannot be three negative roots and *c'* cannot be unstable.
For *F'(K)<0,* it is necessary that $s_l(1-s_l)\varepsilon - s_{ng}(1-s_{ng})\lambda>0$ for the trace to be positive. This determines that c_2 is necessarily negative. Therefore, there cannot be three negative roots and *c''* cannot be unstable.
Thus, the roots of the characteristic equation are always a combination of positive and negative values. This steady state is, consequently, conditionally stable.

Proof of proposition 8

Since the determinant of the homogeneous all-ecolabel equilibrium *d''* is $|J|_{d''} = F'(K)\beta\Omega$, this is equal to zero when $\Omega=0$ evaluated in that point, that is to say, when $\delta(0,\hat{K}) + R(1,\hat{K}) = c(a_l)$, or equivalently, $R(1,\hat{K}) = c(a_l)$.

Proof of proposition 9

Given that the determinant of a heterogeneous equilibrium composed of ecolabel and non-green firms *a''* is $|J|_{a''} = -s_l(1-s_l)\alpha[F'(K)(\lambda-\varepsilon)+N\cdot a_l(\sigma+\theta)]$, this is equal to zero when $F'(K)(\lambda-\varepsilon)+N\cdot a_l(\sigma+\theta)=0$, or $(\lambda-\varepsilon)+\frac{N\cdot a_l}{F'(K)}(\sigma+\theta)=0$, evaluated at that point.

Proof of proposition 10

When *a''* and *c''* coincide in a single equilibrium, in that equilibrium $(s_{ng}+s_l)=1$ (as defined by *a''*) and $\alpha=0$ (as defined by *c''*).
The determinant of *a''*, $|J|_{a''} = -s_l(1-s_l)\alpha[F'(K)(\lambda-\varepsilon)+N\cdot a_l(\sigma+\theta)]$, is equal to zero when $\alpha=0$. Then, *a''* becomes non-hyperbolic.
The determinant of *c''*, $|J|_{c''} = s_{ng}s_l(1-s_{ng}-s_l)[-F'(K)\lambda\varepsilon+N(a_l-a_g)\lambda\theta-N\cdot a_g\sigma\varepsilon]$, is equal to zero when $(s_{ng}+s_l)=1$. Then *c''* becomes non-hyperbolic.
Thus, when *a''* and *c''* coincide in one equilibrium, it is non-hyperbolic.