ENVIRONMENTALLY FRIENDLY PRODUCTION AND LABELLING

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Firms' strategic behaviour regarding environmentally friendly practices is modelled using evolutionary game theory and replicator dynamics. We elaborated the choice of technology and labelling practices when firms performed as bounded rational agents and considered revision of their strategies only occasionally. The framework is information asymmetric because the consumers do not observe a firm type directly, but can infer it indirectly through the market price. We explored the technology strategies of eco-labelled firms. We found that there was an interior unstable state which divided the basins of attraction of two exterior stable states, one where all certified firms were polluting, and another where all certified firms were non-polluting. In order to foster adoption of non-polluting technology, the government should introduce more frequent monitoring and higher penalties for non-alignment with eco-label requirements. We also explored adoption of eco-labels when technology is given and we found an interior evolutionary stable state where certified and non-certified polluting firms co-existed. That is, a part of the polluting firms mimicked non-polluting ones by eco-labelling their own products. Finally, we conclude that the government may choose between an improvement in minimum environmental standards or stricter monitoring in order to de-stimulate false eco-labelling of polluting firms.

1. INTRODUCTION

The scope of this paper is the interrelation between the choice of environmentally friendly technology and eco-labelling practices. A framework with credence good is applied, so that the actual product type (green or brown) is not observed by the consumer, even after purchase and consumption, but is known by the firm. The concept of credence good is usually applied to study

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environmental technology choice. For example, Sengupta (2012:470) makes a difference between dirty and clean producer technology which "is known to the firm but not to the consumer". One of the seminal papers on information asymmetry in the market is Akerlof (1970) who points out that the trade of such goods can be limited. For this reason, various kinds of tools are implemented in order to resolve or avoid the information asymmetry problem, among which certification and labelling schemes (OECD, 2011:20 and 29). Some of alternative instruments are signalling through prices (Janssen and Roy, 2010; Bagwell and Riordan, 1991), word-of-mouth and networks (DiMaggio and Louch, 1998; Dranove and Zhe Jin, 2010:938; Ottman et al., 2006:34), advertising (Hertzendorf and Overgaard, 2004) and horizontal differentiation (Daughety and Reinganum, 2008). There are two important issues about eco-labelling, emphasised by many authors (for instance Schumacher (2010:2203), Lozano et al (2010:2526), and Trevers and Jones (2010:491)): the costs of labelling and reliability, which may be correlated. Usually, the consumers cannot inspect if the products reach environmental standards even after purchase. The purpose of eco-labels is to provide reliable information to the consumers about the sustainability of the product. However, even the eco-labels may fail to diminish the information asymmetry (Van Amstel et al., 2008).

We study the relationship between the environmentally friendly production and eco-labelling taking into account that eco-labels are costly and may be unreliable. We study two questions: how the eco-labelling practices affect the adoption of environmentally friendly technology, and how the choice of technology affects the adoption of eco-labels. The two questions could be studied simultaneously by exploring the co-evolution of environmentally friendly technology and eco-labels adoption. However, for the matter of tractability, in this paper we approach to them as two separate processes. Firstly, we investigate the adoption of environmentally friendly technology assuming that eco-labels are given. Next, we explore the adoption of eco-labels assuming that the eco-friendly technology is given. As a future research, one needs to explore if the insights obtained by such a simplified analysis still hold within a dynamically more complex framework.

Unreliability of eco-labels is captured by allowing the polluting firms to obtain an eco-label, but with an additional cost. We use evolutionary game theory which is a suitable analytical tool if one wishes to represent the firms as bounded-rational. Thus, an implicit assumption is that a firm only occasionally revises its eco-labelling and technology choices and the revision is based on the performance comparison with a similar firm. We follow similar evolutionary models with the hawk-dove games (as in Bowles (2004:79)). Mishra (2006:353) develops an evolutionary framework to explore the relationship between pollution and corruption. Lozano et al. (2010) also use the evolutionary game theory to model the co-evolution of traders with different quality and certifying practices when there is the information asymmetry. The consumers can only imperfectly distinguish between different types of producers. They also suppose that the fraction of different types affects the market price. Some authors, like Lozano et al. (2010), focus on the choice of non-polluting firm to adopt an eco-label. We extend this model by allowing the possibility that the polluting firm obtains such a certificate as well since the reliability of the eco-labels is questioned in the literature. That is, the eco-labels should decrease the information asymmetry but in practice many eco-labels are not reliable which comes from the fact that they do not manage to distinguish perfectly between polluting and non-polluting firms.

We look at the technology choice when eco-labelling schemes do not exist, and we find that the firms converge to the brown technology. If we suppose that eco-labelling choice is given, certified green and brown firms may exist, but only under the condition that an additional cost of brown firm certification is equal to the cost of environmentally friendly practices. Instead, it is more likely that all firms converge to the same technology, polluting or non-polluting. In order to assure the adoption of non-polluting technology, the government can raise impediments to certification of polluting firms, such as more frequent monitoring and higher penalties for corrupt behaviour and non-alignment with eco-label requirements.

When instead we assume a given technology, we find that certified and non-certified brown firms co-evolve. However, this interior stationary state increases if the willingness to pay for green products increases due to, for example, environmental education or due to the improved access to information about the health effects of different products, because such a shift will motivate the brown firms to mimic green firms in terms of eco-labelling. Finally, the government may choose between an improvement in minimum environmental standards or stricter certification controls and audits to de-stimulate false eco-labelling.

2. MODEL

2.1. Players (actors)

There is a population of firms with two traits: environmentally friendly behaviour and eco-labelling practices. Environmentally friendly behaviour refers to the firm's polluting practices, and in this respect there are two types of firms: green and brown. Green (non-polluting) firms take into account environmental impact of their business, and apply necessary measures for its reduction. The environmental impact can be understood as global, as an impact to third parties, or as a direct impact on the consumer through product consumption. Environmental friendliness is costly which we denote by e and which applies to the green firms only. Thus, $e > 0$ is an additional cost of environmentally friendly technology. On the contrary, the brown (polluting) firms avoid such costs by ignoring environmental impacts of their business practices. We do not impose additional assumptions about cost convexity, which in fact would not affect the results.

Population composition is as follows: We define the fractions of particular types of producers within the producer populations. In fact, there are four subgroups: green certified, green non-certified, brown certified and brown non-certified producers. Their fractions sum to one:

$$\alpha = \alpha_C + \alpha_N \qquad (1),$$

$$\beta = \beta_G + \beta_B \qquad (2),$$

where:

- α is a fraction of green firms (and subsequently, $1-\alpha$ is a fraction of brown firms),
- α_C and α_N refer to the fraction of green certified and noncertified firms (respectively),
- β is a fraction of certified firms (and $1-\beta$ is fraction of non-certified firms),
- β_G and β_B refer to the fraction of green and brown certified firms (respectively).

Note that α_C is equivalent to β_G so in the analysis we will use only symbol β_G. The fraction of non-certified brown producers is equal to $1-\alpha_N-\beta_G-\beta_B$. Thus, the analysis in this paper focuses on the population dynamics. We observe how one producer type shifts to another type. This shift is based on the comparison of the payoffs of two types.

We focus on the third-party environmental labelling. We suppose that environmental auditing is imperfect (Schumacher, 2010; Lozano et al, 2010), so that even a polluting firm can obtain an eco-label, but at a higher cost. Thus, the eco-label cost for green and brown firm is c_g and c_b respectively, where $c_g < c_b$.

They are related to the type of firm. The green firm, which faces the cost of environmentally friendly technology *e*, may face the cost of eco-labelling c_g as well. The cost difference reflects additional efforts of the brown firms needed to present them as green ones during the auditing. Furthermore, it also reflects the brown firm's risk to be revealed and punished. Finally, it can also be interpreted as bribes the brown firm needs to pay to the authorities in order to obtain an illegal label. The similar idea is also discussed in Mishra (2006:353). Thus, various interpretations are consistent with the model. Other production costs are for the matter of tractability normalised to zero, so that the total costs of a brown firm without label are zero. We suppose that the producer supply is infinite.

Furthermore, we suppose that the actual producer technology is *ex ante* observable by the producer, but not by the consumer. The consumer knows the share of the producer types within the population, but does not observe the actual technology. Thus, the consumers make buying decisions based on expected utility. Thus, with this respect, we widely adopt modelling framework, such as in McCluskey (2000:5) and Dulleck et al. (2011:530). Consumers perceive the difference between a green and a brown product as a difference in quality, so that they prefer the green one. Such a preference can result from the health concerns about a particular product. Namely, recall that some brown products may affect the consumer directly. However, there are brown products which are harmless for the consumer, but they affect the global environment and/or can be harmful for third parties. The consumers may still prefer the green products to the brown ones because of the existence of environmental preferences (Brecard, 2013:2). For this reason Asche et al (2013:9) distinguish between labels referring to private attributes and labels referring to environmental public goods. A unit money metric consumer utility function is: $\theta - p$, where $\theta \in \{g, b\}$ and $g>b$. As it will be elaborated soon, the exchange is possible only if the price is not higher than the expected consumer utility.

2.2. Matching process

There are two types of matching in this model. The first one refers to the matching between two producers and it is elaborated further in the text. It is a constituting part of every evolutionary game theory model with the replicator dynamics. The second type of matching is specific for the market exchange. Within every period a producer and a consumer are matched. A producer sets the price lower or equal to the consumer's quality expectation. We assume that the producers are price-makers, so that in every single exchange they act as monopolists. In other words, we do not consider the competition case. Later in the text we mention that the firms match, but in order to compare their payoffs and not in order to compete.

2.3. Price

A producer chooses the price taking into consideration his behavioural trait and the profit maximisation. The producer is backward-looking, thus he does not take into account the effect of his choice on the market outcomes. The consumer observes if the product is eco-labelled or not, but the type of technology (green or brown) is not observed. However, the consumer knows the share of particular types within the population of firms in every period. Therefore, the consumer makes buying decisions based on the expectation about technology. $\overline{p}$ is the maximum price at which the consumer is willing to buy an eco-labelled product (which can actually be green or brown):

$$\overline{p} = \mu g + (1 - \mu)b \qquad (3),$$

where $b \leq \overline{p} \leq g$.

During the exchange process within a period the producers do not interact. However, their decisions to switch type affect the consumer expectation, and subsequently it affects the market price $\overline{p}$.

The model is driven by the difference between *b* and *g*, and not by their actual levels. Thus, without loss of generality, we could set *b=0*. However, we proceed without placing any additional assumptions on the actual levels of quality. We implicitly assume that the expected quality is non-negative, and thus *b* should be positive. Furthermore, we implicitly introduce unit demand and money-metric utility function which are the standard assumptions in this class of models (for example Brecard, 2013:4). μ is an updated probability that the firm is green if it holds an eco-label:

$$\mu = \frac{\beta_G}{\beta_G + \beta_B} \qquad (4).$$

Thus,

$$\overline{p} = \frac{\beta_G}{\beta_G + \beta_B} g + \frac{\beta_B}{\beta_G + \beta_B} b \qquad (5).$$

Non-labelled product can be green or brown as well, so its price is denoted by:

$$\bar{q} = \frac{\alpha_N}{1-\beta_G-\beta_B} g + \frac{1-\alpha_N-\beta_G-\beta_B}{1-\beta_G-\beta_B} b \quad (6).$$

2.4. Profits

The firm profit is a difference between the price and accompanying costs. Depending on the firm traits (technology and eco-labelling) the profit is denoted as follows, where πGC, πGN, πBC and πBN refer to green certified, green non-certified, brown certified and brown non-certified firms respectively:

$$\pi_{GC} = \bar{p} - e - c_G \quad (7),$$
$$\pi_{GN} = \bar{q} - e \quad (8),$$
$$\pi_{BC} = \bar{p} - c_B \quad (9),$$
$$\pi_{BN} = \bar{q} \quad (10).$$

In the next section we apply the evolutionary game theory with replicator equation to analyse the model. We comment on the main properties of this approach. It is assumed that the agents sometimes behave rationally, but mostly they follow the already acquired routines. The agents are adaptive and backward-looking. Thus, they do not predict long-term consequences of their choices. In every period only a few agents consider the revision of their strategies. The revision of strategies is based on the comparisons of own payoffs and the payoffs of another agent from the same population but with different traits. At the end of every period the agents match randomly (but this time two firms, and not a firm and a consumer what was previously discussed) and they compare their payoffs. If the payoffs differ, then one of the two agents will with certain probability shift to the opposite type. For a short overview of evolutionary game theory and replicator dynamics, one may consult Pavlinović (2011) and Weibull (1995) for more details.

The effect of the price on profits determines the evolution of the producer types which is studied in the following sections. The fraction of firms with a particular technology or labelling practices is a common knowledge which affects the price of the eco-labelled product. Hence, the firms affect mutual payoffs through the price mechanism. One could observe the dynamics of all four classes of firms, green/brown (non)certified, simultaneously. That is, one could consider the possibility that a firm can at the same time revise its technology and eco-labelling practices. However, for the matter of tractability we consider two variants of the model. The first one is the variant with given eco-labelling practices across the firms, but the firms consider the revision of their technology. Another variant is developed on the assumption that the technology is fixed, but the firms consider the revision of their eco-labelling practices.

3. ADOPTION OF ECO-FRIENDLY TECHNOLOGY

Suppose that eco-labelling practices are already determined across the firms, so that some firms are already involved in such practices. Under such conditions, the adoption of eco-friendly technology among the producers is analyzed. We suppose that the firms compare the payoffs only if they apply the same certification practices. For example, if certified green and brown firms are matched they compare their profits. The one with lower profit alters its technology with some probability. The one with higher profit keeps the existing technology. We define the strategy revision by replicator dynamics equations.

We presume that firms behave as bounded rational agents, in a sense that they only periodically update their behavioural traits and eventually adopt a strategy that brings a higher payoff. In this section we assume that if the firm is brown certified it is going to shift to green certified, even if it would be more profitable to abandon the eco-labelling practice and remain brown. The dynamics of non-certified firms is represented by:

$$\dot{\alpha}_N = \alpha_N (1 - \alpha_N - \beta_G - \beta_B)(\pi_{GC} - \pi_{BC}) \qquad (11).$$

A change in fraction of non-certified green firms is determined by the probability that a non-certified green firm “meets“ the non-certified brown firm, and by the difference in their performance. Thus, if the non-certified green firm performs better, the non-certified brown firm will with certain probability transform its technology to green. There exist several stationary states:

$$1 - \alpha_N - \beta_G - \beta_B = 0 \qquad (12).$$

There may exist an interior stationary state:

$$0 < \alpha^* < 1 \qquad (13),$$

such that:

$$\pi_{GC} = \pi_{BC}\text{, that is } \overline{q} - e = \overline{q} \qquad (14).$$

This equality never holds in the model, because the marginal cost of green firm *e* is supposed to be positive. Thus, it is evident that $\pi_{GC} > \pi_{BC}$. In other words, non-certified green strategy is always dominated by non-certified brown strategy. For this reason, in the subsequent analysis, we will set $\alpha_N = 0$ which will add to the tractability of the analysis. If we look at the stability of the exterior stationary states, we observe that the subpopulation of non-certified firms will always converge to brown technology independently of α_N size because $\pi_{GC} > \pi_{BC}$. In other words, any small perturbations from the stationary state $\alpha_N = 0$ will bring the sub-population of non-certified back to $\alpha_N = 0$ which represents an evolutionary stable state.

On the contrary, evolutionary state $1 - \alpha_N - \beta_G - \beta_B = 0$ is unstable because any small perturbation (an error) will lead the sub-population away from this unstable stationary state. For this reason we proceed assuming $\alpha_N = 0$.

The dynamics of certified firms is represented by:

$$\dot{\beta}_G = \beta_G \cdot \beta_B \left(\pi_{GC} - \pi_{BC}\right) \qquad (15).$$

The stationary states are: $\beta_G = 0$ and $\beta_B = 0$. Under certain conditions there exists an interior stationary state $0 < \alpha^* < 1$. The interior stationary state satisfies the condition:

$$\pi_{GC} = \pi_{BC} \qquad (16).$$

Thus, the interior stationary state exists under a particular condition:

$$\overline{p} - e - c_G = \overline{p} - c_B \qquad (17),$$

that is, if:

$$e = c_B - c_G \qquad (18).$$

However, more probable situation is that the payoffs differ, so that the interior stationary state does not exist. If $\pi_{GC} > \pi_{BC}$ and $e < c_B - c_G$, then the subpopulation of certified firms converges to the exterior stationary state where only certified greens exist and $\beta_B = 0$. Conversely, if $\pi_{GC} > \pi_{BC}$ and $e > c_B - c_G$, then the subpopulation of certified firms converges to the exterior stationary state where only certified browns exist and $\beta_G = 0$. Thus, we can conclude that in situations where the process of obtaining eco-labels is very slow, it is not likely that certified green and brown firms will mix. Instead, it is more likely that certified firms converge to all green or all brown evolutionary stable state.

This, in turn, may considerably affect the firms' equilibrium profits. If the marginal cost of environmentally friendly practice (*e*) is larger than the difference in certification costs of green and brown firms, than, as we already stated, the certified firms will converge toward brown technology which will result in a decrease of the price of eco-labelled product so that $\overline{p} = b$ in the equilibrium. If the utility of green product *g* is sufficiently large relative to *b* and *e*, the brown firms are worse-off then if they had all chosen the environmentally friendly technology. In order to transform the system to the one with green technology as an evolutionary stable state, the government should focus on measures which increase c_B, such as more frequent monitoring and higher penalties for corrupt behaviour and non-alignment with eco-label requirements.

4. ADOPTION OF ECO-LABELS

In the previous section we analysed the choice of technology when the eco-labelling practice is given. Here, we consider the factors which affect the eco-label adoption. In particular, as we concluded in the previous section that it was very likely that green non-certified firms did not exist, in this section we assume that all green firms are certified, and we focus on the adopting eco-label by brown firms. Their choices in the end affect the price of a product with an eco-label, and consequently the profits of green firms.

Thus, we study the following replicator dynamics:

$$\dot{\beta}_B = \beta_B (1 - \beta_B - \beta_G)(\pi_{BC} - \pi_{BN}) \quad (19).$$

The change in fraction of certified brown firms is determined by the probability that a certified brown firm is matched with a non-certified brown firm, and by the difference in their profits.

The stationary states are:

$$\beta_B = 0 \text{ and } 1 - \beta_B - \beta_G = 0 \qquad (20).$$

and, under certain conditions, there exists an interior stationary state $0 < \beta_B^* < 1$. The interior stationary state satisfies the following condition:

$$\pi_{BC} = \pi_{BN} \qquad (21).$$

It follows that:

$$\overline{p} - \overline{q} = c_B \qquad (22),$$

where:

$$\overline{p} = \frac{\beta_G}{\beta_G + \beta_B} g + \frac{\beta_B}{\beta_G + \beta_B} b \qquad (23)$$

and $\overline{q} = b$, since $\alpha_N = 0$.

Thus, at interior stationary state the following holds:

$$\frac{\beta_G}{\beta_G + \beta_B} g + \frac{\beta_B}{\beta_G + \beta_B} b - b = c_B \qquad (24),$$

$$\frac{\beta_G g + \beta_B b}{\beta_G + \beta_B} = c_B + b \qquad (25),$$

$$\beta_G g + \beta_B b = (\beta_G + \beta_B) c_B + (\beta_G + \beta_B) b \qquad (26).$$

The interior stationary state is:

$$\beta_B^* = \frac{\beta_G (g - b - c_B)}{c_B} \qquad (27).$$

β_B^* must be between zero and one, thus for some parameter values the interior stationary state does not exist and all the brown firms either eco-label their products, or leave the product without an eco-label. We check for the Lyapunov stability of the interior stationary state by deriving the difference in profits $\pi_{BC} - \pi_{BN}$ by β_B:

$$\partial_{\beta_B}(\pi_{BC} - \pi_{BN}) = \frac{-\beta_B(g-b)}{\beta_G + \beta_B} < 0 \qquad (28).$$

Since the derivative is negative, we conclude that the interior stationary state is evolutionary stable. Small perturbations from this interior stationary state are corrected and lead back again to the interior stable state. For example, if $\beta_B < \beta_B^*$, then the profit of certified brown firm is above the profit of non-certified brown firm, so that when these two firms match, the non-certified firm converts to certified. Thus, the fraction of certified brown firms increases and the system converges to β_B^*.

Conversely, when $\beta_B > \beta_B^*$, then the profit of non-certified brown firm is above the profit of certified brown firm so, so that whenever these two firms match, certified firm abandons its eco-labelling practices. Thus, again the system converges to β_B^*.

The intuition for such a process comes from the fact that the fraction of eco-labelled brown, which is a common knowledge, affects directly the consumer expectations about environmental friendliness of a certified product. Therefore, an increase in β_B decreases the price of eco-labelled product so that the profit of brown certified firm decrease. The opposite also holds, so that when β_B decreases the profit of brown certified firm increases.

The interior stationary state increases if willingness to pay for green products increases. The consumer environmental-regarding preference may be affected by environmental education or by improved access to information about the health effects of different products. Such a shift will motivate the brown firms to mimic green firms in terms of eco-labelling.

The effect of an increase in willingness to pay for brown product and brown firm cost of eco-certification affects negatively the interior state. An improvement in minimum environmental standards may de-stimulate the brown firms to certify as greens, since the price of non-certified product increases. Alternatively, the same effect can be reached by restricting the certification controls and audits. Therefore, the government may consider which of these two measures is more effective.

5. CONCLUSION

Eco-labelling has become a widely applied tool to foster environmentally friendly business. However, the concerns about eco-labels trustfulness urges for a more comprehensive analysis of firms' motives with respect to eco-friendly business practices and eco-labelling. We find that if there are no labelling options, all the firms should abandon costly environmentally friendly practices. On the contrary, if (third-party) eco-labelling schemes exist, depending on the relevant costs, the eco-certified firms may turn all to green or all to brown. More specifically, if the additional cost of green production exceeds the additional cost the polluting firm incurs to obtain an eco-label, then all the certified firms choose to pollute, and the opposite also holds.

We analysed the choice of brown firm to certify its products, and we find that under reasonable conditions some part of polluting firms mimic the non-polluting firms by eco-labelling their products. The government may choose between an improvement in minimum environmental standards or stricter certification controls and audits to destimulate the brown firms to mimic the green firms. A fruitful direction for future research is to explore the evolution of both, adoption of green technology and eco-labels simultaneously, and especially to investigate the eco-labelling choice of the green firms in such a framework.

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PROIZVODNJA I OZNAČAVANJE PROIZVODA POGODNIH ZA OKOLIŠ

Sažetak

U ovom se radu modelira strateško ponašanje poduzeća s aspekta praksi pogodnih za okoliš pomoću evolucijske teorije igara i dinamike replikatora. Raspravlja se o izboru tehnologije i praksi označavanja proizvoda, kada se poduzeća ponašaju kao akteri koji djeluju s ograničenom racionalnošću i svoje strategije razmatraju samo povremeno. Teorijski okvir podrazumijeva informacijsku asimetriju, jer kupci ne percipiraju poduzeće direktno, već donose indirektne zaključke na temelju tržišne cijene. Stoga se analiziraju tehnološke strategije poduzeća koja koriste ekološko označavanje. Rezultati ukazuju da postoji nestabilno unutarnje stanje, koje odjeljuje područja privlačenja između dva vanjska stabilna stanja – jednog, u kome sva poduzeća zagađuju te drugog, u kome niti jedno poduzeće ne zagađuje. Kako bi se poduprlo prihvaćanje tehnologija pogodnih za okoliš, vlade bi trebale češće nadgledati stanje i nametati više kazne za poduzeća koja ne poštuju zahtjeve ekološkog označavanja. Također se analiza prihvaćanje ekološkog označavanja, kada je tehnologija konstantna, pri čemu je pronađeno interno evolucijsko stanje, u kome su postojala i poduzeća koja ne zagađuju, kao i zagađivači. Pritom su zagađivači prikrivali svoju praksu ekološkim označavanjem vlastitih proizvoda. Na kraju se zaključuje da vlade mogu birati između povećanja minimalnih okolišnih standarda i strožeg nadzora, kako bi se destimuliralo lažno ekološko označavanje od strane zagađivača.