Is Ecolabelling a Reliable Environmental Policy Measure?*

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Abstract

Ecolabel award schemes have become increasingly popular. Their rationale is to enable (concerned) consumers to identify "green" products. By so doing, ecolabelling should stimulate environmental innovation, and induce firms to reduce the supply of conventional (polluting) products. Our analysis however points out that the two phenomena are not necessarily correlated. Through a dynamic model of investment decisions, the paper outlines the situations under which ecolabelling could induce perverse effects (increased investment in conventional technologies), and examines whether setting quantitative restrictions on the issuing of labels could constitute an antidote.

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1 Introduction.

Although ecolabelling - i.e. the award, by a competent body, of a mark of environmental quality to firms voluntarily submitting an application - is no longer a novelty[1], there is still a lack of empirical and theoretical analysis aimed at assessing or predicting its effectiveness in terms of reducing the supply of "polluting products".

While noting a positive correlation between the spread of "environmental innovations" and the establishment of eco-label award schemes, the few analyses available admit that it is difficult to establish, ex post, whether such innovations would have occurred in any case in those sectors with a greater concentration of firms that have applied for - and have been awarded with- ecolables (OECD, 1991).

Nevertheless, the prevailing view is that, though it cannot be considered a panacea, ecolabelling would be a useful accessory in environmental policy, able to encourage spontaneous processes of environmental innovation, and a virtuous "environmental competition" among firms. For instance, given the latent (increasing) demand (willingness-to-pay) for green products, eco-label award schemes should serve two purposes at once. On the one hand, labels would allow for consumer recognition of these products: something which would otherwise be difficult, if not impossible, to achieve given the complex nature of the environmental impact of products along their entire life cycle. On the other hand, as certification highlights more environmentally benign alternatives and provides consumers with guidance, firms with a greater propensity to innovate would be able to reap the benefits deriving from the transformation of their productive processes, and at the same time "penalize" competitors that try to create a green image by merely making superficial or cosmetic changes on their products.

While we agree with this view of the potential advantages of ecolabelling, we feel it is worthwhile to deepen the analysis of its impact, particularly by identifying the conditions on which the success of the initiative depends. For instance, in one of the rare attempts at theoretical analysis of ecolabel award schemes, Mattoo and Singh (1994) have pointed out the risk that

[1]The first official ecolabelling programme was set up in Germany in 1978. Similar initiatives were later undertaken in other OECD Countries. In 1992 the Council of European Communities, through Regulation n.880/92, set up a Community eco-label award scheme, with the aim of creating the conditions for ultimately establishing an effective single environmental label in the Community.

ecolabelling might lead to an increase in the supply of polluting products, due to possible increases in their relative prices induced by a greater supply of green products, following the establishment of an ecolabelling programme.

While also outlining the potential perverse effects of ecolabelling, our analysis is based on a structurally different model. Unlike Matto and Singh's work, we propose a dynamic model, inspired by the literature on investment decisions in conditions of uncertainty, referring in particular to the connections between these decisions and the theory of real options.[2]. In this context, the consequences of an ecolabel award scheme are interpreted in the light of the impact it might have not only on the firm's technological mix, but also on the timing of investment in different (conventional and green) technologies. For instance, we show that to assess the overall impact of ecolabelling, both investment decisions before and after the label is awarded should be considered.

The paper is structured as follows. The following section presents the basic model which is characterized by the hypothesis that adopting a non-polluting technology (using "green capital") is a necessary and sufficient condition for a firm to be awarded with an ecolabel, even though it adopts conventional technologies at the same time. Our analysis shows that, in certain conditions, particularly when the ecolabel projects a positive image over the entire firm, and not merely on the certified product(s), ecolabelling may lead to an expansion of investment in conventional technology before the label itself is awarded.

In section 3 we examine the consequences of setting quantitative restrictions, i.e. granting ecolables only to a subset of agents able to submit products that meet the requirements necessary for receiving the label itself. Such restrictions, applied in a number of Countries, are generally aimed at encouraging competition and/or preventing firms already holding dominant market positions from increasing their market power. In this paper, on the other hand, we examine the question whether rationing actually constitutes also an antidote to the potential perverse effects of ecolabelling. In the conclusion we make some remarks on the policy implications deriving from the analysis.

[2] The relationship between irreversible investment decisions and option theory has been developed in the works of Bertola (1988) and Dixit (1989), and by He and Pindyck (1992) with regard to choices of technological flexibility. For an extension of this literature to investment decisions regarding the transition from a polluting technology to a green one, see Dosi and Moretto (1997a; 1998).

2 The basic model.

Consider a good, with a stochastically evolving demand, that may be produced by two different processes, i.e. by using two different types of capital, $K^p$and K^g, with unitary sunk costs equal to r and $r+b$ ($b \geq 0$), respectively.

Adoption of the first type (K^p) translates into supply of a "polluting product" (in the production and/or consumption phase), while the second (K^g) allows for production of a "green" product. The firm may adopt both technologies simultaneously, setting up two distinct production lines, but is unable to adapt and reconvert the "polluting capital". In other words, K^p and K^g are fixed factors and the investment decisions are irreversible.

As a reference scheme for analysing firm's investment decisions we shall take the two-period model proposed by Abel, Dixit, Eberly and Pindyck (1996), which points out the connections between the literature on irreversible investment decisions in conditions of uncertainty and the theory of real options.

Let us assume that the relatively more costly green technology only becomes available in the second period. Moreover, we assume that investment in "green capital", K^g , is only justified by the ecolable, without which the firm's innovative effort would not be recognised and rewarded by consumers (willing-to-pay more for green products).

In the first period the firm should decide how much polluting capital to invest (K_1^p), knowing that in the second period it may either increase the stock ($K_2^p > K_1^p$) or else abandon it, i.e. by adopting only non-polluting processes (using K^g alone), or maintaining both production lines.

As both types of capital are fixed and their earnings are uncertain, the possibility of varying K^p in the second period may be interpreted as a *call option,* while the possibility of buying green capital may be seen as a *flexible production option.*

The optimal choice of K_1^p is therefore the result of *ex ante* maximization of the firm's value, a value constituted by both the discounted flow of expected profits and the above-mentioned option values.

The firm's profits in the first and second period are defined respectively by the following *revenue functions*: $R^p(K_1^p)$ and $R(K_2^p, K_2^g; \theta)$, where θ - by hypothesis, common to both productive processes and hence independent of the technology adopted - is a stochastic variable with an accumulated distribution $\Phi(\theta)$, $\theta \in \Theta \subseteq \mathbf{R}$, representing a profitability index capturing the effects of possible demand shocks.

Assumption 1. $R^p(K_1^p)$ is a continuous, strictly increasing and concave function in K_1^p .Moreover, Inada's conditions hold, i.e.: $\lim_{K^p \to 0} R_K^p = +\infty$, $\lim_{K^p \to \infty} R_K^p = 0$.
Assumption 2. $R(K^p, K^g; \theta)$ is a continuous, strictly increasing function in the set of variables (K^p, K^g, θ). $R_{K^g}(K^p, K^g; \theta) \geq 0$ and $R_{K^g}(K^p\ , K^g; \theta) \geq 0$ and continuous and strictly decreasing in K^p and K^g, and continuous and strictly increasing in θ. $R(.)$ meets Inada's conditions: $\lim_{K^i \to 0} R_{K^i} = +\infty$, $\lim_{K^i \to \infty} R_{K^i} = 0,\ i = p, g$.
Assumption 3. $\lim_{K^g \to 0} R(K^p, K^g; \theta) = R^p(K^p; \theta)$, while $\lim_{K^p \to 0} R(K^p, K^g; \theta) = R^g(K^g, \theta)$. Moreover, there is a value $\theta' \geq 0$ beyond which $R_K^p < R_K^g$.

The first two assumptions are standard. As to the third one, it indicates that, *coeteris paribus*, i.e. for whatever realisation of $\theta > \theta'$, the marginal profitability of the green capital, due to the ecolabel, is higher than that of the polluting capital.

In the second period, given the inherited stock of polluting capital K_1^p, following Assumption 2 it is possible to identify a *critical value for the profitability index*, $\hat{\theta}$, so that the following equation holds:

$$R_{K^p}(K_1^p, K_2^g(\hat{\theta}); \hat{\theta}) = r \tag{1}$$

Since for every optimal stock $K_2^g(\theta) > 0$, in the interval $S = \left\{\theta : \theta \geq \hat{\theta}\right\}$ the value of a marginal unit of polluting capital is equal to its installation cost, S may be interpreted as the firm's instantaneous investment in additional units of polluting capital. Similarly, the complement $S^c = \left\{\theta : \theta < \hat{\theta}\right\}$ indicates the interval in which the firm finds it optimal to invest in green capital. In this case, $K_2^p(\theta) = K_1^P$, since $R_{K^p}(K_1^p, K_2^g(\theta); \theta) < r$, and $K_2^g(\theta) > 0$.

Given these hypotheses, and assuming a constant discount rate, $\gamma > 0$, the following proposition may be prooved:

Proposition 1 *If, despite contemporaneous use of polluting capital, investment in green capital is a necessary and sufficient condition for a firm to be awarded with an ecolabel, the firm's ex ante value is defined by the following expression:*

$$V(K_1^p) = R^p(K_1^p) + \gamma \int_{-\infty}^{\hat{\theta}} \{R(K_1^p, K_2^g(\theta); \theta) - (r + b) K_2^g(\theta)\} d\Phi(\theta) +$$

$$\gamma \int_{\hat{\theta}}^{+\infty} \{R(K_2^p(\theta), K_2^g(\theta); \theta) - r[K_2^p(\theta) - K_1^p] - (r+b)K_2^g(\theta)]\} d\Phi(\theta)$$

or rearranging,

$$V(K_1^p) = V_{NL}(K_1^p) + \tag{2}$$

$$+\gamma \left[\int_{-\infty}^{\hat{\theta}} \{R(K_1^p, K_2^g(\theta); \theta) - (r+b)K_2^g(\theta)\} d\Phi(\theta) - \int_{-\infty}^{\hat{\theta}_0} R^p(K_1^p; \theta) d\Phi(\theta) \right]$$

$$+\gamma \left[\int_{\hat{\theta}}^{+\infty} \{R(K_2^p(\theta), K_2^v(\theta); \theta) - r[K_2^p(\theta) - K_1^p] - (r+b)K_2^v(\theta)]\} d\Phi(\theta) \right.$$

$$\left. - \int_{\hat{\theta}_0}^{+\infty} \{R^p(K_2^p(\theta); \theta) - r[K_2^p(\theta) - K_1^p]\ \} d\Phi(\theta) \right]$$

Proof: see Appendix A.

$V_{NL}(K_1^p)$ represents the value of the firm if, in the second period, there was no "technological flexibility" (i.e. the possibility of adopting the green technology) i.e., under our assumptions, if the award of an ecolabel was not foreseen. That is,

$$V_{NL}(K_1^p) = R^p(K_1^p) + \gamma \int_{-\infty}^{\hat{\theta}_0} R^p(K_1^p; \theta) d\Phi(\theta)$$

$$+\gamma \int_{\hat{\theta}_0}^{+\infty} \{R^p(K_2^p(\theta);\theta) - r[K_2^p(\theta) - K_1^p]\ \} d\Phi(\theta).$$

$\hat{\theta}_0$ represents the critical value ("trigger value") of the profitability index deriving from condition $R_K^p(K_1^p;\hat{\theta}_0) = r$.

Hence, analysing (2), it is possible to interpret the second and the third term on the r.h.s. as a "*quasi-rent*" which the firm may gain thanks to (the possibility of adopting the green technology, made profitable by) the ecolabel award scheme. The problem of optimization in the first period may be represented as follows:

$$K_1^p = \arg\max \left[V(K_1^p) - rK_1^p\right]. \tag{3}$$

Maximization of (3) allows us to determine the optimal stock of polluting capital in the first period. The first order condition is defined by the following expression:[3]

$$V'(K_1^p) \equiv V'_{NL}(K_1^p) + \gamma \int_{-\infty}^{\hat{\theta}} [R_{K^p}(K_1^p, K_2^g(\theta);\theta) - r] d\Phi(\theta) \tag{4}$$

$$-\gamma \int_{-\infty}^{\hat{\theta}_0} [R_K^p(K_1^p;\theta) - r] d\Phi(\theta) = r.$$

Equation(4) expresses the marginal value of the investment in polluting capital in the first period with the sum of its marginal value, if ecolabelling were not foreseen, $V'_{NL}(K_1^p)$,and the value reached - in the interval of "non

[3]Following Assumption 2 it is easy to check that:

$$V''(K_1^p) = R''^p(K_1^p) + \gamma \int_{-\infty}^{\hat{\theta}} R_{K^pK^p}(K_1^p, K_2^v(\theta);\theta) d\Phi(\theta) < 0,$$

That is, for whatever $r > 0$, there is always a single value of K_1^p which satisfies condition (4).

investment" $(-\infty,\hat{\theta}]$ - by its net expected marginal earnings in the second period when the programme is in force, $\int_{-\infty}^{\hat{\theta}}[R_{K^p}(K_1^p,K_2^g(\theta);\theta)-r]d\Phi(\theta)\leq 0$, net of the value reached (regarding the non-investment interval - $(-\infty,\hat{\theta}_0]$ - by the net expected marginal earnings with no ecolabelling, $\int_{-\infty}^{\hat{\theta}_0}[R_K^p(K_1^p;\theta)-r]d\Phi(\theta)\leq 0$. Indicating as $K_{NL,1}^p$ the stock of polluting capital which the firm would acquire in the first period if there were no ecolabelling [4], the following proposition may be proved.

Proposition 2 *If, despite contemporaneous use of polluting capital* ($K_2^p > 0$)*, investment in green capital* ($K_2^g > 0$) *is a necessary and sufficient condition for a firm to be awarded with an ecolabel, this induces,*

i) a reduction, in the period before the label is granted, in investments in polluting capital, if $R_{K^pK^g} < 0$. *That is:*

$$V'(K_1^p) < V'_{NL}(K_1^p) \qquad \Rightarrow \qquad K_1^p < K_{NL,1}^p$$

where NL indicates the absence of an ecolabel award scheme.

ii) an increase, in the period before the label is granted, in investments in polluting capital, if $R_{K^pK^g} > 0$. *That is:*

$$V'(K_1^p) > V'_{NL}(K_1^p) \qquad \Rightarrow \qquad K_1^p > K_{NL,1}^p$$

Proof: see Appendix B.

Proposition 2 thus shows an interesting result. In particular, the possibility that the establishment of an ecolabel award scheme, and the consequent expectation of receiving the label, might induce perverse effects, i.e. an expansion of the stock of polluting capital before the label is granted, with permanent consequences due to the irreversibility of the investment. This possibility is linked to the existence of "marketing complementarity" among products produced by the two production lines.

If a "marketing complementary relationship" exists ($R_{K^pK^g} > 0$), that is the ecolabel is expected to project a positive image onto the entire firm, increasing the profitability of all the capital invested, then the firm will find it

[4] That is, the stock of polluting capital deriving from condition $V'_{NL}(K_{NL,1}^p) = r$.

convenient to expand its stock of polluting capital before adopting the green technology and receiving the label ($K_1^p > K_{NL,1}^p$).

On the other hand, if a "substitutability relationship" exists ($R_{K^pK^g} < 0$), that is if the label exclusively leads to enhancement of the green production line -and does not have a positive effect on the profitability of the conventional production lines- then the eco-label award scheme will produce the desired effects, that is it will stimulate a reduction in polluting capital ($K_1^p < K_{NL,1}^p$).[5].

The risk of undesirable consequences of a ecolabel award schemes, due to misleading advertising, has been noticed by legislators. EEC Council Regulation n.880/92, for example, allows firms to refer to the ecolabel in advertising, but "only in relation to the specific product for which it was awarded " (art. 16, 1).

Legal provisions of this kind attenuate, but do not eliminate, the risk of perverse effects of ecolables.. Despite the formal prohibition to use them as a means of promoting the entire firm, the fact that consumers are likely to associate the certified product(s) with the manufacturer's name may project an unjustified positive ("green") image for the firm as a whole when it is able to exhibit an officially certified product in its catalogue.

In other words, the risk of ecolabel award schemes not only failing to produce appreciable consequences - i.e. not stimulating adequate diffusion of green technologies - but even inducing perverse effects -i.e. an increase in the profitability of conventional products- is connected with behavioural patterns by firms and consumers alike which are difficult to foresee and not always controllable ex post, as such behaviour is not easily covered by the specific regulations on the use of ecolabels and the general rules on misleading advertising.

Hence there is a need to lay down some remedies that are more effective than formal restrictions, such as the prohibition in the above-mentioned Article 5 of the Community Regulation, in order to counter, or at least attenuate, the risk that a measure, aimed not only at stimulating environmental inno-

[5] As the the label transfers process innovation into product innovation, the positivity of the "*quasi-rent*" $V(K_1^p) - V_{NL}(K_1^p)$ follows a similar path to equation (1) in Athey and Schmutzler (1995), where, for a given quantity, implementing a product design innovation is beneficial if it raises the demand curve, and a process innovation is beneficial if it lowers the average cost curve. Therefore we can interpret the difference $V'(K_1^p) - V'_{NL}(K_1^p)$ as the marginal effect of the label on the returns to K_1^p. That is, the effect of implementing an innovative technology (product and/or process innovation) on marginal revenue as in equation (3) in Athey and Schmutzler (1995).

vation but also at reducing the supply of polluting products, should produce undesirable consequences.

The most radical solution would clearly be to award ecolables only to firms able to demonstrate the environmental compatibility of all their activities, and not merely the eco-compatibility of a subset of productions lines (Dosi and Moretto, 1997b).

A less radical solution would be to adopt selection procedures for candidates which, though not imposing an absolute restriction on the use of polluting technologies, would allow labels to be awarded after controls not only on the specific features of the product(s) proposed for certification, but also a valuation of the firm's general behaviour, rewarding those firms that have shown a greater ("historical") propensity to adopt environmentally-friendly behaviour[6].

3 Ecolabelling and quantitative restrictions.

Quantitative restrictions are applied in some Countries endowed with an ecolabel award scheme. In order words, ecolables are only granted to a restricted number of applicants submitting products meeting the "ecological" criteria established for each product group.

Such rationing - which in certain cases is explicitly laid down in the legislation, or more often is a general practice - is applied either by refusing to award labels to firms already holding dominant market positions (as in Germany for example), or by awarding the label only to a certain percentage of applicants, by taking into account the presumed market share of products proposed for certification with respect to overall demand in the sector (as practised in Canada) (OECD, 1991).

Rationing is generally aimed or justified as a means of preventing firms awarded with ecolabels - which in fact give their holders a kind of exclusive

[6] Dosi and Moretto (1997b) analyse the consequences of a scheme where the decision to award the label is subordinated not only to controls on the specific features of the product proposed for certification, but also to a review of the firm's past behaviour. In particular, assuming that the probability of obtaining the label is inversely correlated to the stock of polluting capital used by the firm in the past, they show that in these circumstances the potentially perverse effects of ecolabelling would be reduced. That is, if $R_{K^pK^v} > 0$, the optimal stock of polluting capital in the first period (K_1^p) will be, *coeteris paribus,* lower than what it would be if the introduction of green capital in the second period were a necessary and sufficient condition for granting the label.

right and competitive advantage - from gaining dominant positions, with the undesirable consequences, in terms of equity and efficiency, that have been widely explored in the literature on patents and licences.

In the following section we shall attempt to analyse whether quantitative restrictions also constitute an antidote with respect to the possible perverse effects of ecolabelling outlined above, that is an expansion of the stock of polluting capital before the label is granted.

In our partial equilibrium framework, rationing may be formally represented as a higher constraint on the firm's stock of green capital in the second period. For instance, since, under our assumptions, buying green capital is only justified by the consequent award of an ecolabel - without which the firms' innovative effort would not be recognized and rewarded by consumers - rationing ecolabels is equivalent to limiting investments in green capital.

With respect to the basic model, the timing of the firm's problem may be summarized as follows. In the first period the competent body announces that labels will be granted in the second period to a limited number of candidates able to submit products meeting the conditions for awarding the certificate of environmental quality (i.e. use of green capital, even if conventional production lines are kept alive). At the beginning of the second period emerges the true value of the profitability index θ and the firm decides, given its inherited stock of polluting capital (K_1^p), whether to invest in green capital. However, whatever its choice, the overall stock of green capital in the second period may not exceed the upper limit $\bar{K}^g$, that is $K_2^g \leq \bar{K}^g$.

As mentioned above, the aim is to see whether establishing the restraint $K_2^g \leq \bar{K}^g$ is an antidote with respect to the possible perverse effects of ecolabelling mentioned in proposition 2, i.e. higher investments in polluting capital in the first period. As such effects are linked to the existence of a relationship of "marketing complementarity" among the two products ($R_{K^pK^g} > 0$), we shall now go on to focus on this case alone.

Establishing the constraint $K_2^g \leq \bar{K}^g$ implies, with respect to the basic model, integrating condition (1) with the following expression:

$$R_{K^g}(K_2^p(\tilde{\theta}), \bar{K}^g; \tilde{\theta}) = r + b \tag{5}$$

Equations(1) and (5) thus allow us, depending on K_1^p and $\bar{K}^g$, to identify three new intervals of investment whose boundaries are defined by certain critical values of the profitability index θ. However, characterization of such intervals is more complex with respect to the previous cases as it requires a specification of the revenue function.

In general, however, it is possible to identify two situations, characterized respectively by "sequentiality" ($\hat{\theta} < \tilde{\theta}$) and "non-sequentiality" of investment decisions in the two technologies" ($\hat{\theta} > \tilde{\theta}$) (see Appendix C).

In the first case ("sequentiality" henceforth) it is possible to identify an interval in which it is convenient to invest in green capital alone, and a second one in which it is worthwhile to invest in green capital while increasing the stock of polluting capital, and a further interval in which it is only possible to increase the stock of polluting capital as the upper limit $\bar{K}^g$ has been reached.

In the second case ("non-sequentiality"), as well as an interval in which it is convenient to invest in green capital alone, there is a second interval in which it is not worthwhile to invest either in green capital or to increase the stock of polluting capital, and a third interval where it may again be convenient to increase the stock of polluting capital.

Each of these situations corresponds to different ex ante firm values. Indicating these values respectively as $V_{seq}(K_1^p)$ and $V_{nseq}(K_1^p)$, we obtain:

Proposition 3 *In case 1 ("sequentiality"), the firm's ex-ante value is defined by the following expression:*

$$
\begin{aligned}
&V_{seq}(K_1^p) = V_{NL}(K_1^p) \; + \\
&\quad +\gamma\left[\int_{-\infty}^{\hat{\theta}} [R(K_1^p, K_2^g(\theta);\theta) - (r+b)K_2^g(\theta)]d\Phi(\theta) - \int_{-\infty}^{\hat{\theta}_0} R^p(K_1^p;\theta)d\Phi(\theta)\right] \qquad (6)\\
&\quad +\gamma\left[\int_{\hat{\theta}}^{\tilde{\theta}} \{R(K_2^p(\theta), K_2^g(\theta);\theta) - r[K_2^p(\theta) - K_1^p] - (r+b)K_2^g(\theta)]\}d\Phi(\theta)\right.\\
&\qquad + \int_{\tilde{\theta}}^{+\infty} \{R(K_2^p(\theta), \bar{K}^g(\theta);\theta) - r[K_2^p(\theta) - K_1^p]\}d\Phi(\theta)\\
&\qquad \left. - \int_{\hat{\theta}_0}^{+\infty} \{R^p(K_2^p(\theta);\theta) - r[K_2^p(\theta) - K_1^p]\;\}d\Phi(\theta)\right],
\end{aligned}
$$

In case 2 ("non-sequentiality"), the firm's ex-ante value is defined by the expression:

$$V_{nseq}(K_1^p) = V_{NL}(K_1^p) + \tag{7}$$

$$+\gamma\left[\int_{-\infty}^{\tilde{\theta}} [R(K_1^p, K_2^g(\theta);\theta) - (r+b)K_2^g(\theta)]d\Phi(\theta) + \right.$$

$$\left. + \int_{\tilde{\theta}}^{\hat{\theta}} \{R(K_1^p, \bar{K}^g;\theta)\}d\Phi(\theta) - \int_{-\infty}^{\hat{\theta}_0} R^p(K_1^p;\theta)d\Phi(\theta)\right]$$

$$+\gamma\left[\int_{\hat{\theta}}^{+\infty} \{R(K_2^p(\theta), \bar{K}^g(\theta);\theta) - r[K_2^p(\theta) - K_1^p]\}d\Phi(\theta)\right.$$

$$\left. - \int_{\hat{\theta}_0}^{+\infty} \{R^p(K_2^p(\theta);\theta) - r[K_2^p(\theta) - K_1^p]\ \}d\Phi(\theta)\right],$$

Proof: see Appendix C.

It is immediate to compare with equation (2) of the basic model. In both cases the constraint of expandibility of green capital alters the composition of the "quasi-rent" that the firm may gain following introduction of the label. However, due to the sequentiality of the investment decisions in the two technologies, in case 1 the optimal condition for K_1^p is identical to that of the basic model, i.e.:

$$V'_{seq}(K_1^p) = V'(K_1^p) \equiv V'_{NL}(K_1^p) + \gamma \int_{-\infty}^{\hat{\theta}} [R_{K^p}(K_1^p, K_2^g(\theta);\theta) - r]d\Phi(\theta) \tag{8}$$

$$-\gamma \int_{-\infty}^{\hat{\theta}_0} [R_K^p(K_1^p;\theta) - r]d\Phi(\theta) = r.$$

In case 2, on the other hand, the optimal condition for K_1^p is transformed as follows:

$$V'_{nseq}(K_1^p) \equiv V'_{NL}(K_1^p) + \gamma \int_{-\infty}^{\hat{\theta}} [R_{K^p}(K_1^p, K_2^g(\theta); \theta) - r] d\Phi(\theta) - \gamma \int_{-\infty}^{\hat{\theta}_0} [R_K^p(K_1^p; \theta) - r] d\Phi(\theta)$$

$$+\gamma \left[\int_{\tilde{\theta}}^{\hat{\theta}} [R_{K^p}(K_1^p, \bar{K}^g; \theta) d\Phi(\theta) - \int_{\tilde{\theta}}^{\hat{\theta}} [R_{K^p}(K_1^p, K_2^g(\theta); \theta) d\Phi(\theta) \right] = r,$$

or suitably rearranging:

$$V'_{nseq}(K_1^p) = V'(K_1^p) + \gamma \left[\int_{\tilde{\theta}}^{\hat{\theta}} [R_{K^p}(K_1^p, \bar{K}^g; \theta) d\Phi(\theta) - \int_{\tilde{\theta}}^{\hat{\theta}} [R_{K^p}(K_1^p, K_2^g(\theta); \theta) d\Phi(\theta) \right] = r. \tag{9}$$

Moreover, as complementarity of the production lines, (i.e. $R_{K^p K^g} > 0$), implies $R_{K^p}(K_1^p, K_2^g(\theta); \theta) > R_{K^p}(K_1^p, \bar{K}^g; \theta)$, the term in square brackets is negative, giving rise to the following proposition:

Proposition 4 *In case 1 ("sequentiality") setting quantitative restrictions is ineffective, i.e. it does not attenuate the perverse effects of ecolabelling deriving from the existence of a complementary relationship between the two product lines.*

In case 2 ("non-sequentiality"), setting quantitative restrictions contributes to attenuating the perverse effects of ecolabelling, that is:

$$V'_{nseq}(K_1^p) < V'(K_1^p) \quad \Rightarrow K_{nseq,1}^p < K_1^p$$

Proof: straightforward from (8) and (9).

An algebraic example may be useful for interpreting the results proposed above. Consider a Cobb-Douglas type of revenue function:

$$R = (\theta)^{+\alpha} (K^p)^{+\beta} (K^g)^{+\rho} \qquad , \quad \alpha + \beta + \rho = 1 \quad , \quad \theta \in \mathbf{R}_+.$$

Applying (1) and (5), and taking account of the general first order conditions for optimal choice of the capital mix, the following equation may be set:

$$\frac{\hat{\theta}}{\tilde{\theta}} = \frac{\rho}{\beta} \frac{r}{r+b} \frac{K_1^p}{\bar{K}^g}, \tag{10}$$

Hence, depending on the value - whether higher or lower than one - taken on by the term appearing on the r.h.s.of (10), we may return to one of the two cases illustrated previously. That is, respectively, the case of "sequentiality" ($\hat{\theta} < \tilde{\theta}$), and that of "non-sequentiality" ($\hat{\theta} > \tilde{\theta}$).

Since the term $\frac{r}{r+b}$ is, by hypothesis, less than, or at most equal to one, and given the exogenous parameters β and ρ representing, respectively, the market share of conventional ($\frac{R_{K^p} K^p}{R}$) and green outcomes ($\frac{R_{K^g} K^g}{R}$) , the value of the relation $\frac{\hat{\theta}}{\tilde{\theta}}$ will depend on the restrictions imposed on expansion of the green technology, that is on the ratio $\frac{K_1^p}{\bar{K}^g}$.

If the agency responsible for awarding the eco-labels believes that the demand (willingness to pay) for green products is relatively small with respect to the overall industry's turnover ($\rho < \beta$, or $\frac{\rho}{\beta} < 1$), only severe rationing (that is $\frac{K_1^p}{\bar{K}^g} > 1$) will be an effective measure in countering the perverse effects of ecolabelling. Less severe rationing ($\bar{K}^g > K_1^p$) will be required, on the other hand, if the demand for green products is expected to prevail ($\frac{\rho}{\beta} > 1$).

4 Final remarks.

Over the last twenty years official ecolabel award schemes, aimed at encouraging the supply of green products, have become widespread.

The popularity of these initiatives depends in general on the implicit assumption that adoption of clean technologies is necessarily accompanied by a reduction in investments in conventional production processes and hence a reduction in pollutant emissions.

Our analysis however points out that the two phenomena are not necessarily correlated. In other words, the adoption of green production processes and the supply of more environmentally begnign products may be accompanied not only by conservation of conventional production lines - a phenomenon generally accepted by the current systems for granting ecolables - but also by an increase in investment in conventional technologies.

The occurrence of a perverse effect due to ecolabelling depends on whether there is a “marketing comlementarity” between the different production lines. In particular, if the firm expects that the ecolabel - obtained for a specific product - will project a positive image over the entire firm, then ecolabelling, while encouraging environmental innovations, could at the same time induce increased investment in conventional technologies.

The risk of a distorted use of ecolabels with consequently perverse effects has been noted by legislators. However, this risk is connected with behavioural patterns by firms and consumers that are difficult to prevent ex post and are not always easy to account for in the specific rules on using the labels and the more general legislation on misleading advertising. Hence there is a need to take more effective measures, in particular stricter selection of candidates.

In the second part of the paper we examined the consequences deriving from restricting the awards of ecolabels to a sub-set of firms that meet the requirements laid down, in order to ascertain whether rationing is an effective antidote for the possible perverse effects of ecolabelling deriving from the ”complementary relationship” between conventional products and green (labelled) ones.

Our analysis has shown that setting quantitative restrictions may contribute to avoiding or at least attenuating the risk of increasing investments in traditional technologies, provided that rationing is applied taking account of market conditions. In particular, if the demand for green (labelled) products is (expected to be) relatively low in terms of market share, rationing should be particularly strict in order to be effective.

A Appendix: proof of proposition 1.

To describe this choice, operatively we first analyse the choice in the second period, for a given value of stock of polluting capital inherited from the first period. Hence the choice in the first period depends on the choice in the following one.

- **Second period**

In the second period, once the realization of the profitability index θ is known, the firm maximizes its short term profits by choosing an optimal mix between the two types of capital. The conditions of optimality are:

$$\begin{aligned} R_{K^p}(K_2^p(\theta), K_2^g(\theta); \theta) &= r \\ R_{K^v}(K_2^p(\theta), K_2^g(\theta); \theta) &= r + b \end{aligned} \tag{11}$$

However, given the stock of inherited capital K_1^p, following Assumption 2 we are able to identify a critical value for the profitability index $\hat{\theta}$, so that the following equation holds:

$$R_{K^p}(K_1^p, K_2^g(\hat{\theta}); \hat{\theta}) = r \tag{12}$$

That is, depending on K_1^p and for every optimal value of $K_2^g(\theta) > 0$, equation (12) identifies two intervals of investment. In the first one, defined by the inequality $\theta > \hat{\theta}$, it is optimal for the firm to acquire new units of both capital typologies up to the point where the marginal profits are equal to the marginal costs as in (11). In this case $K_2^p(\theta) > K_1^p$ e $K_2^g(\theta) > 0$. In the second case, expressed by $\theta < \hat{\theta}$, the firm finds it optimal to invest in green capital alone. In this case, $K_2^p(\theta) = K_1^P$, since $R_{K^p}(K_1^p, K_2^g(\theta); \theta) < r$, e $K_2^g(\theta) > 0$. Moreover, since Assumption 2 implies that $R_{K^p\theta} > 0$, applying the theorem of functions implicit to (12) and using Assumption 3, we get:

Lemma 1 *(i)* $\frac{d\hat{\theta}}{dK_2^g} \begin{cases} > 0 & if \;\; R_{K^pK^g} < 0 \\ < 0 & if \;\; R_{K^pK^g} > 0 \end{cases}$, *and*

(ii) $\lim_{K_2^g \to 0} \hat{\theta}(K_2^g) = \hat{\theta}_0$, *where* $\hat{\theta}_0$ *is given by* $R_K^p(K_1^p; \hat{\theta}_0) = r$

The lemma shows that the interval where it is optimal to invest in both types of capital, $\theta > \hat{\theta}$, is reduced with increases in investment in green capital when a substitutability relationship prevails. On the other hand, this relation expands when the two product lines are complementary to one another.

- **First period**

The value of the firm in period 1, $V(K_1^p)$, is defined as the expected discounted value of current profits in the two periods when the stock of capital in period 1 is given by K_1^p. Recalling (12), this value may be expressed as follows:

$$V(K_1^p) = R^p(K_1^p) + \gamma \int_{-\infty}^{\hat{\theta}} \{R(K_1^p, K_2^g(\theta); \theta) - (r+b)K_2^g(\theta)\} d\Phi(\theta) +$$

$$\gamma \int_{\hat{\theta}}^{+\infty} \{R(K_2^p(\theta), K_2^g(\theta); \theta) - r[K_2^p(\theta) - K_1^p] - (r+b)K_2^g(\theta)]\} d\Phi(\theta),$$

or rearranging taking account of lemma 1, we obtain the expression reported in the text:

$$V(K_1^p) = V_{NL}(K_1^p) + \tag{13}$$

$$+\gamma \left[\int_{-\infty}^{\hat{\theta}} [R(K_1^p, K_2^g(\theta); \theta) - (r+b)K_2^g(\theta)] d\Phi(\theta) - \int_{-\infty}^{\hat{\theta}_0} R^p(K_1^p; \theta) d\Phi(\theta) \right]$$

$$+\gamma \left[\int_{\hat{\theta}}^{+\infty} \{R(K_2^p(\theta), K_2^g(\theta); \theta) - r[K_2^p(\theta) - K_1^p] - (r+b)K_2^g(\theta)]\} d\Phi(\theta) \right.$$

$$\left. - \int_{\hat{\theta}_0}^{+\infty} \{R^p(K_2^p(\theta); \theta) - r[K_2^p(\theta) - K_1^p]\ \} d\Phi(\theta) \right],$$

where $V_{NL}(K_1^p)$ indicates the value of the firm if, in the second period, there is no possibility of switching to the green technology, or in our case, if ecolables are not granted. That is:

$$V_{NL}(K_1^p) = R^p(K_1^p) + \gamma \int_{-\infty}^{\hat{\theta}_0} R^p(K_1^p; \theta) d\Phi(\theta)$$

$$+\gamma \int_{\hat{\theta}}^{+\infty} \{R^p(K_2^p(\theta); \theta) - r[K_2^p(\theta) - K_1^p] \} d\Phi(\theta).$$

B Appendix: proof of proposition 2.

For convenience we may rewrite the optimal condition for K_1^p :

$$V'(K_1^p) \equiv V'_{NL}(K_1^p) + \gamma \int_{-\infty}^{\hat{\theta}} [R_{K^p}(K_1^p, K_2^g(\theta); \theta) - r] d\Phi(\theta) \qquad (14)$$

$$-\gamma \int_{-\infty}^{\hat{\theta}_0} [R_K^p(K_1^p; \theta) - r] d\Phi(\theta) = r.$$

Equation (14) expresses the marginal value of the polluting factor in period 1 as the sum of the marginal value of the polluting factor should the label not be granted, $V'_{NL}(K_1^p)$, plus the differences between the expected value of marginal profits in period 2 when the label is granted (regarding the non-investment interval $(-\infty, \hat{\theta}])$, $\int_{-\infty}^{\hat{\theta}} [R_{K^p}(K_1^p, K_2^g(\theta); \theta) - r] d\Phi(\theta) \leq 0)$, and the expected value of marginal profits in period 2 without the label (regarding the non investment interval $(-\infty, \hat{\theta}_0])$, $\int_{-\infty}^{\hat{\theta}_0} [R_K^p(K_1^p; \theta) - r] d\Phi(\theta) \leq 0)$. As in both cases, in the non investment interval the marginal profits are lower than r, the expected value in turn is negative, so that:

$$\int_{-\infty}^{\hat{\theta}} [R_{K^p}(K_1^p, K_2^g(\theta);\theta) - r] d\Phi(\theta) - \int_{-\infty}^{\hat{\theta}_0} [R_K^p(K_1^p;\theta) - r] d\Phi(\theta) < 0 \text{ if } \hat{\theta} > \hat{\theta}_0,$$

$$\int_{-\infty}^{\hat{\theta}} [R_{Kp}(K_1^p, K_2^g(\theta);\theta) - r] d\Phi(\theta) - \int_{-\infty}^{\hat{\theta}_0} [R_K^p(K_1^p;\theta) - r] d\Phi(\theta) > 0 \text{ if } \hat{\theta} < \hat{\theta}_0.$$

Then, application of lemma 1 proves proposition 2 in the text.

C Appendix: proof of proposition 3.

The proof follows identification of the intervals of investment which are more complex to characterize than the previous case (unrestricted labelling), as the revenue function has to be specified. As pointed out in the text, in general two situations may be identified. The first one ("sequentiality of investment decisions") is characterized by the following marginal conditions:

$$\begin{cases} R_{K^p} < r \\ R_{K^g} = r + b \end{cases} \qquad \theta \in S_1, \tag{15}$$

$$\begin{cases} R_{K^p} = r \\ R_{K^g} = r + b \end{cases} \qquad \theta \in S_2,$$

$$\begin{cases} R_{K^p} = r \\ R_{K^g} > r + b \end{cases} \qquad \theta \in S_3,$$

where $S_1 = \left\{\theta : \theta < \hat{\theta}\right\}$ is the interval where it is convenient to invest in green capital alone; $S_2 = \left\{\theta : \hat{\theta} \leq \theta < \tilde{\theta}\right\}$ is the interval where it is convenient both investing in green capital and increase the stock of polluting capital; finally, $S_3 = \left\{\theta : \theta \geq \tilde{\theta}\right\}$ is the interval where the upper limit $\bar{K}^g$ has been reached and the firm cannot expand its green capital.

The second situation ("non-sequentiality of investment decisions") is characterized, on the other hand, by the following marginal conditions:

$$\begin{cases} R_{K^p} < r \\ R_{K^g} = r + b \end{cases} \qquad \theta \in S_1, \tag{16}$$

$$\begin{cases} R_{K^p} < r \\ R_{K^g} > r + b \end{cases} \qquad \theta \in S_2,$$

$$\begin{cases} R_{K^p} \leq r \\ R_{K^g} > r + b \end{cases} \qquad \theta \in S_3,$$

where, in this case, $S_2 = \left\{\theta : \tilde{\theta} \leq \theta < \hat{\theta}\right\}$ indicates the interval where it is neither convenient to increase the stock of polluting capital, nor to increase the stock of green capital as the upper constraint $\bar{K}^g$ has been reached. Making use of these three intervals it is immediate to write equations (6) and (7) in the text.

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