

# **On the Use of Consumer Information to Address Externalities: The Economics of Eco-Labeling**

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## ABSTRACT

An intriguing alternative to traditional methods for regulating externalities is the provision of information about firms' environmental attributes. An increasingly important example of this approach is "eco-labeling," where a third party certifies firms' products. Such schemes are currently used in a variety of countries. This paper investigates the equilibria that may occur with eco-labeling, and the attendant welfare effects. I model certification as a noisy test, with green firms more likely to pass than brown firms. While likely to increase the fraction of green units in the market, the introduction of eco-labeling can either increase or decrease welfare.

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## 1. Introduction

An emerging literature in environmental economics points to the potential for information to aid in the control of externalities. For example, some have argued that publicly available information can induce firms to become more environmentally friendly because of market pressures (Arora and Cason, 1996, 1999; Konar and Cohen, 1997, 2001). Indeed, Tietenberg [1998] refers to this possibility as the “third wave” of pollution control.

There is abundant evidence that consumers express a willingness to pay a premium to “protect the environment” (Cairncross, 1992; Cason and Gangadharan, 2001; Haji-Gazali and Simula, 1994; Levin, 1990; Wasik, 1996; Winterhalter and Cassels, 1993). Firms that use environmentally friendly production techniques would like to capitalize on this demand, but they face a problem of asymmetric information. Consumers cannot typically tell the type of production process a particular firm has used, so they can’t determine when it is environmentally friendly. Since the environmentally friendly technique is generally more costly, firms would be disinclined to choose such a technique, with larger pollution flows resulting. One possible remedy for this informational asymmetry is for firms to make use of “eco-labeling.” With eco-labeling, a third party – either some governmental agency, or a non-governmental organization – certifies a vendor’s product as the result of an environmentally friendly process.

In the last decade or so, eco-labels have emerged in a wide range of countries (Karl and Orwatt, 2000; OECD, 1998; Vossenaar, 1997). Some of these certification programs have become quite popular, as with the German “Blue Angel,” Japanese “Eco-Mark,” Swedish “Environmental Choice,” and “Nordic Swan” programs (OECD, 1998). These eco-labels are often applied to products where consumers would generally be individually unable to determine the environmental friendliness of the product, for example the biodegradability of a paper product,

or of the production process itself. Many of the eco-labeling programs currently in operation consider production-related criteria in their assessments of firms that seek certification.

It is tempting to regard this certification as absolute, as in Karl and Orwatt [2000], Mattoo and Singh [1994], Robertson [2000] or Swallow and Sedjo [2000]. But this only makes sense if the third party can perfectly identify compliance with the eco-label's avowed standards at a reasonable cost. Indeed, in many of the current eco-labeling programs provided by a third party, the firm's compliance with the environmentally friendly process is gauged by random monitoring. But when monitoring is random, certification must be viewed as noisy. In principle, the certifying organization would like to employ absolute standards, in practice this is not feasible.<sup>1</sup> The certifying party cannot be certain that the firm always uses environmentally friendly techniques, nor that the monitoring scheme is able to perfectly detect any violations. Even if the certifying process is perfectly able to evaluate a product's compliance with the test's standards, there is considerable doubt that the standards are perfectly correlated with "environmental friendliness" (Arda, 1997; Morris, 1997). Nevertheless, it seems reasonable that environmentally friendly firms would be more likely to obtain certification.

I model this effect by assuming firms are either environmentally friendly (green) or not (brown), and that the certification process yields a positive report with some probability. Green firms are more likely to pass the certification test than are brown firms; all firms must pay the same fee if they wish to pursue certification. In each of the versions of the model I consider there are two issues of interest. First, what are the potential equilibria, and how are they related to the underlying parameter configurations? Second, what are the welfare implications of the introduction of an eco-labeling option? Of related interest are the comparative static effects of

increases in test cost or test accuracy (as measured by increased pass rates for green units or decreased pass rates for brown units).

I start off the discussion by considering a simple version of the model, wherein green units are always certified and brown units pass with a positive probability that is less than one, and in which all sellers in a particular cohort have the same cost structure. In this version, characterization of the equilibrium outcome is relatively straightforward. There are three possible configurations. If certifying costs are sufficiently large, sellers of brown units do not pursue the eco-label, and a separating equilibrium emerges. If certifying costs are sufficiently small, all sellers seek certification, and a pooling equilibrium results. Finally, for intermediate values of certifying costs the equilibrium is partial pooling: all green sellers and some brown sellers pursue the eco-label. An interesting and counter-intuitive outcome of this third class is that small increases in certifying costs can make green sellers better off. This result obtains because such increases reduce the number of brown sellers that seek certification, which raises the price paid to certified units. Indeed, under fortuitous circumstances, this effect is sufficiently strong as to raise net surplus.

I next consider a version of the model where brown units are never certified, but some green sellers do not pass the test. As in the first version of the model, some parameter configurations support a separating equilibrium, some support a pooling equilibrium, and still others support a partial pooling equilibrium. As with the first variant, welfare can be either higher or lower in a separating equilibrium than in the no-information equilibrium; unlike the first variant, there is no difference between the pooling equilibrium and the no-information equilibrium. Also in contrast to the first variant, net surplus is always lower in the partial

pooling equilibrium than in the no-information equilibrium. In addition, increases in test cost in this variant of the model always lower welfare.

These simple models are easily extended to a model in which green sellers pass probabilistically (albeit with a greater chance than brown units). Again, there are parameter configurations that support a separating equilibrium, configurations that support a pooling equilibrium, and combinations that support a partial pooling equilibrium. In both the pooling and partial pooling classes, there are two possible outcomes. For example, if test costs are particularly high, it could be an equilibrium for no firms to test, as with the pooling equilibrium in the second variant; for lower costs, it could be an equilibrium for all firms to test, as in the first variant. There are also two styles of partial pooling, one in which all green and some brown sellers seek the eco-label (as in the first variant of the model), and one in which some green and all brown sellers eschew testing (as in the second variant). Output and welfare effects are correspondingly analogous, though less dramatic, to those earlier versions.

Finally, I relax the assumption of homogeneity of costs in the context of the third variant of the model. In the resultant equilibrium, in each cohort the typical firm generally strictly prefers to pursue certification or to not pursue certification; a population-based mixed strategy results. Firms sort themselves according to their production costs. Firms with relatively low production costs are most likely to seek an eco-label, while firms with relatively large costs choose to remain unlabeled. While considerably more complex than the earlier versions, again the outcome is qualitatively similar, suggesting the earlier results are robust to the initially assumed cost homogeneities.

Putting aside any production externalities associated with the two techniques, the socially efficient level of production for green (respectively, brown) products equates supply with full-

information price  $P_G$  (respectively,  $P_B$ ). In the original no-information equilibrium, it is apparent that an inefficiently large quantity of brown products is produced, and an inefficiently small quantity of green products. Evidently, any change that lowers the quantity of brown units while raising the quantity of green units would reduce deadweight loss. In the models I consider, eco-labeling commonly leads to an increase in the production of green units, and a decrease in the production of brown units. This output rationalization occurs because green sellers expect a larger price, and brown sellers a lower price, than in the no-information equilibrium. But the test is costly, and so any putative welfare gains from moving the volumes of green and brown units towards their first-best (full information) levels must be compared against aggregated testing costs. In each variant of the model, there are parameter configurations under which the introduction of eco-labeling would lead to an increase in net surplus. But in each variant, for any of the possible classes of equilibria, there are parameter configurations in which aggregate certification outweighs any welfare gains from output rationalization.<sup>2</sup>

These welfare remarks are tied to the market imperfection associated with asymmetric information. But there is an additional issue. Since pollution levels are larger with the brown technology, it will generally cause larger production externalities. This effect is not fully captured by a divergence between prices for green and brown units, which are more the result of consumer preferences than any explicit recognition of externalities. Moreover, to the extent that eco-labeling is more attractive to green sellers than brown sellers, brown firms might be inclined to adapt their production technology over time. That is, the potential benefits from eco-labeling could easily be larger in the long run than in the short run. I discuss these two complications in the concluding remarks.

## 2. The Certifying Model

Consider a competitive market for a product that can either be produced using an environmentally friendly (green) technology, or by a relatively dirty (brown) technology. Some consumers would be willing to pay extra for green products, so the demand curve for green products lies above the demand curve for brown products. While these demand curves might be expected to slope downward, for expositional simplicity I assume that they are perfectly elastic, with prices fixed at  $P_G$  and  $P_B$  for green and brown products, respectively. This assumption allows a sharper focus on the incentives to pursue eco-labeling, without materially affecting the results.

I assume that production costs are convex in output. Accordingly, supply curves for green and brown products are upward sloping, reflecting increasing marginal costs for each technique. For now, I assume that all green firm has the same cost function  $c_G(q)$ ; similarly, every brown firm faces the cost function  $c_B(q)$ . Because green production is more expensive,  $c_G(q) > c_B(q)$  for any positive output  $q$ . To focus the discussion on the potential information effects of eco-labeling, I make the simplifying assumption that  $c_G(q) = \alpha c_B(q)$ , with  $\alpha > 1$ . Each firm's output is private information, which precludes consumers from drawing inferences about a firm's technology on the basis of its output. These latter two assumptions greatly simplify the discussion that follows. The value of  $\alpha$  is assumed to be common knowledge, so that all agents can calculate the equilibrium expected outputs of green and brown products, and the associated rational expectations prices. There are exogenously fixed numbers of potential brown and green firms,  $N_B$  and  $N_G$ ; this can be interpreted as assuming a short-run perspective. I discuss the likely effect of relaxing this assumption in the concluding remarks.

Before describing the mechanics of the testing equilibrium, I first discuss the outcome in the no-information equilibrium. In the absence of third-party information about production techniques, consumers cannot distinguish a given product's type. Accordingly, market price is a weighted average of the price consumers would pay for a green product and the price they would pay for a brown product, if they were perfectly informed regarding product type. Let  $Q_{G0}$  and  $Q_{B0}$  represent the quantities of green and brown products in the no-information equilibrium, respectively. These quantities are identified from the supply curves for the two types of producer, based on the price  $P_0$ . The supply curves, in turn, depend on the underlying assumptions regarding firms' flexibility. Market price is then

$$P_0 = \theta_0 P_G + (1 - \theta_0) P_B, \text{ where} \quad (1)$$

$$\theta_0 = Q_{G0} / (Q_{G0} + Q_{B0}) \quad (2)$$

equals the fraction of green markets on the market in the no-information equilibrium. For later reference, let  $\pi_{k0}$  denote the profits earned by a typical type  $k = G$  or  $B$  seller in the no-information equilibrium.

Now suppose that a third party offers to provide information about a firm's product, at a specified cost. To this end, the third party employs a certification test. For expositional concreteness, I suppose that the test involves monitoring of some attribute of the production process, such as emissions, that is correlated with the production technology. Since it is prohibitively costly to monitor continuously, the third party monitoring is conducted in a fashion analogous to random monitoring of emissions by a government agency. With random monitoring, it is conceivable that the third party could mistakenly certify some brown firms as environmentally friendly. On the other hand, if the test is only imperfectly correlated with the "green-ness" of the technology, there is the possibility of a false negative as well – that some

green firms will be mistakenly failed. Even so, it stands to reason that the probability that a green firm would pass the test,  $\phi_G$ , is larger than the probability that a brown firm would pass the test,  $\phi_B$ :  $1 \geq \phi_G > \phi_B > 0$ . I assume that seeking certification costs  $A > 0$  for both types of firms.<sup>3</sup>

Three possible classifications can result from the certifying process. A firm can be certified, and thereby receive the price  $P_c$ ; it can seek certification but fail, and then receive the price  $P_f$ ; or it can elect not to pursue certification, and thereby receive the price  $P_{un}$ . All prices are formed endogenously, via rational expectations. Accordingly, the values of the three prices depend on consumers' predictions of the conditional probability that a randomly selected unit is green, given that it is labeled as c, f or un. Under plausible conditions, consumer expectations would be such that failed units and untested units were lumped together as "unlabeled."<sup>4</sup> In such a scenario, only two prices prevail:  $P_c$  and  $P_{un}$ .

In the discussion that follows, I denote the total supply of green (respectively, brown) units by  $Q_G$  (respectively,  $Q_B$ ). Likewise, the quantity of green (brown) units that are tested is  $Q_{Gt}$  ( $Q_{Bt}$ ). Prior to observing any labels, the *ex ante* probability that a randomly selected unit is green equals

$$\theta = Q_G / (Q_G + Q_B). \quad (3)$$

This probability is associated with the *ex ante* expected price,

$$P_0' = \theta P_G + (1 - \theta) P_B. \quad (4)$$

I denote the probability that a randomly selected unit is green, conditional on it being eco-labeled, by  $\mu$ . The probability that a randomly selected unit is green, conditional on it being unlabeled, is  $\nu$ . Using Bayes' law, these posterior probabilities may be calculated as

$$\mu = \text{pr}(G|c) = \text{pr}(c|G)\theta / \text{pr}(c),$$

$$\nu = \text{pr}(G|un) = \text{pr}(un|G)\theta / \text{pr}(un),$$

where  $\text{pr}(c|G)$  is the probability that a unit will be certified, conditional on its seller being green,  $\text{pr}(c)$  is the marginal probability of observing a certified unit,  $\text{pr}(un|G)$  is the probability that a unit will be unlabeled, conditional on its seller being green, and  $\text{pr}(un)$  is the marginal probability of observing an unlabeled unit. It is easy to see that  $\text{pr}(c|G) = \phi_G Q_{Gt} / Q_G$  and  $\text{pr}(c) = (\phi_G Q_{Gt} + \phi_B Q_{Bt}) / (Q_G + Q_B)$ ; it follows that

$$\mu = \phi_G Q_{Gt} / (\phi_G Q_{Gt} + \phi_B Q_{Bt}); \quad (5)$$

$$v = (Q_G - \phi_G Q_{Gt}) / (Q_G - \phi_G Q_{Gt} + Q_B - \phi_B Q_{Bt}). \quad (6)$$

Moreover, there are only two possibilities: a unit is either certified or it is unlabeled; therefore,  $\text{pr}(un) = 1 - \text{pr}(c)$  and  $\text{pr}(un|G) = 1 - \text{pr}(c|G)$ . Combined with eqs. (5) and (6), these remarks imply

$$\mu p(c) + v(1 - p(c)) = \theta. \quad (7)$$

As  $\phi_G > \phi_B$  by assumption, it follows that  $\mu > v$ ; as  $p(c) < 1$  it is then clear that  $\mu > \theta > v$ .

Calculation of equilibrium requires the determination of rational expectations prices.

These prices are based on the conditional probabilities  $\mu$  and  $v$  according to:

$$P_c = \mu P_G + (1 - \mu) P_B; \quad (8)$$

$$P_{un} = v P_G + (1 - v) P_B. \quad (9)$$

Since  $\mu > \theta > v$ , the information produced by the test leads to a higher price for eco-labeled units and a lower price for unlabeled units than the *ex ante* price. The information from the test is therefore useful, in the sense that it moves expected prices towards the full-information prices. That said, a determination of the impact of eco-labeling upon the various quantities requires a comparison of the equilibrium with no-information against the testing equilibrium.

Each firm chooses its output level to maximize expected profits, based on its type, the price it will receive, and its decision as to pursue the eco-label or not. If the firm produces a

positive level, it will be where price equals marginal cost; if variable profits are negative at this level, however, the firm will opt to produce nothing. I denote the typical type  $k$  firm's privately optimal output level by  $q_k^*(P_k)$ , where  $P_k$  is the price the firm anticipates receiving. If the firm has its product tested, and passes, then  $P_k = P_c$ ; if it enters the untested segment, or if it fails the test, then  $P_k = P_{un} = P_B$ . It will be convenient to refer to the typical type  $k$ 's optimal output as  $q_k^*$  if the product has received the eco-label (and hence is paid the price  $P_c$ ) and  $q_k^{**}$  if it has not (in which case it is paid  $P_{un}$ ). Let  $\pi_k^*$  represent the profit a type  $k$  firms when it receives the price  $P_c$  and produces  $q_k^*$ , and  $\pi_k^{**}$  the profit a type  $k$  firms when it receives the price  $P_{un}$  and produces  $q_k^{**}$ :

$$\pi_k^* = P_c q_k^* - c_k(q_k^*), \quad (10a)$$

$$\pi_k^{**} = P_{un} q_k^{**} - c(q_k^{**}). \quad (10b)$$

he expected payoff from testing is

$$\begin{aligned} \Pi_k^* &= \phi_k \pi_k^* + (1 - \phi_k) \pi_k^{**} - A \\ &= \pi_k^{**} + \phi_k (\pi_k^* - \pi_k^{**}) - A, \end{aligned} \quad (11)$$

while the (certain) payoff from not testing equals  $\pi_k^{**}$ . The difference between these two payoffs measures the anticipated gain from pursuing the eco-label. This expected gain depends on the probability of passing the test, the nature of costs, the cost parameter, and the test cost:

$$\begin{aligned} W_k &= \Pi_k^* - \pi_k^{**} \\ &= \phi_k \{P_c q_k^* - c_k(q_k^*) - [P_{un} q_k^{**} - c(q_k^{**})]\} - A. \end{aligned} \quad (12)$$

Under plausible circumstances,  $W_G > W_B$ , so that sellers of green units are more inclined to seek the eco-label than are sellers of brown units.<sup>5</sup>

Assuming  $W_G > W_B$ , all green units are certified whenever any brown sellers seek the eco-label. Write the equilibrium fraction of brown sellers that seek the eco-label as  $\lambda_B$ . From eq. (5), one then infers that

$$\mu = N_G q_G^* / [N_G q_G^* + \phi_B \lambda_B N_B q_B^*]. \quad (13)$$

If no sellers of brown units seek certification,  $\mu = 1$ ; if all brown sellers pursue the eco-label, so that  $\lambda_B = 1$ , then  $\mu = \underline{\mu} \equiv N_G q_G^* / [N_G q_G^* + \phi_B N_B q_B^*]$ . In the former case,  $P_c = P_G$ ; let  $P_c = \underline{P}_c$  in the latter case. These two cases represent the extremes; if some, but not all, brown sellers pursue certification, then  $P_c$  lies between these two values.

### 3. Model 1: Green units always pass

I start the discussion by assuming the certification test is perfectly able to identify green units and then pass them, i.e.  $\phi_G = 1$ . With this assumption, it is immediate that  $v = 0$ , and hence  $P_{un} = P_B$ . Since this version of the model provides the most attractive opportunity for green sellers, I assume they earn strictly positive profits from certifying. (If this were not the case, they would not pursue certification in the variant of the model where  $\phi_G < 1$ , so there would be little point in discussing that version.)

Let the value  $q_k^*$  takes when price equals  $P_B$  be  $\underline{q}_k^*$ ; similarly, write the value  $q_k^*$  takes when price equals  $P_G$  as  $\bar{q}_k^*$ . Define

$$\underline{A}_1 = P_G \bar{q}_B^* - c_B(\bar{q}_B^*) - [P_B \underline{q}_B^* - c_B(\underline{q}_B^*)], \text{ and} \quad (14a)$$

$$\bar{A}_1 = P_G \bar{q}_G^* - c_G(\bar{q}_G^*) - [P_B \underline{q}_G^* - c_G(\underline{q}_G^*)]. \quad (14b)$$

Notice that both expressions are uniquely determined by the (exogenous) consumer valuations of green and brown units,  $P_G$  and  $P_B$ . These expressions represent the maximal gain a seller could receive from certification, with (14a) the relevant expression for brown sellers, and (14b) the

relevant expression for green sellers. Suppose that  $\phi_B \underline{A}_1 \leq A \leq \bar{A}_1$ , so that test cost was at least as large as the maximal gain brown sellers could realize, but no larger than the largest gain green sellers could obtain. If test cost falls in this range, then a separating equilibrium obtains: all green sellers seek the eco-label, and all brown sellers place their products in the uncertified segment of the market. Relative to the no-information equilibrium, it is clear that green sellers must produce a larger amount, and brown sellers a smaller amount. These two effects are welfare-enhancing. But the net impact on welfare is ambiguous. In the separating equilibrium, the equilibrium price for certified units – all of which are green – equals  $P_G$ , and so consumer surplus is nil for buyers of green units. Likewise, consumer surplus is nil for buyers of brown units, since the equilibrium price for unlabeled units – all of which are brown – equals  $P_B$ . Net surplus can therefore be measured by producer surplus, less test costs. In the no-information equilibrium, expected consumer surplus is also nil.<sup>6</sup> Accordingly, the welfare impact from the introduction of eco-labeling boils down to the net effect on firms' profits.

Consider first the possibility that  $A$  is close to  $\bar{A}_1$ . In this event, green sellers' profits are only slightly smaller than the profit they would earn at the price  $P_B$ , while brown sellers' profits are determined by  $P_B$ . If the no-information price is larger than  $P_B$ , which will naturally be the case so long as some green sellers participate, then both types of sellers are made worse off. Accordingly, welfare (net of test costs) would be smaller in the separating equilibrium than in the no-information equilibrium.  $\phi_B \underline{A}_1$  are cancelled out by the test cost.  $\phi_B \underline{A}_1$ . Clearly, in this context an increase in test cost lowers welfare.

Consider next the possibility that  $A$  is close to  $\phi_B \underline{A}_1$ . If the pass rate for brown sellers is relatively small, then a separating equilibrium could emerge even if  $A$  were quite small. Now, there is a deadweight loss associated with the no-information equilibrium (associated with too

much production by brown sellers, and too little by green sellers). On the other hand, there is no deadweight loss in the separating equilibrium (gross of aggregate test costs). It follows that net surplus must rise if test costs are sufficiently small, which is possible if  $\phi_B$  is small. Of course, all this really says is that society is better off with eco-labeling if it is accurate and nearly free. The point is, there are parameter configurations under which separating equilibria exist that make society worse off, and there are parameter configurations under which separating equilibria exist that make society better off. Moreover, all else equal, increases in the test cost are unambiguously deleterious.

Next, define  $q_{k2}^*$  as the value  $q_k^*$  takes when  $P_c = \underline{P}_c$  for  $k = G$  or  $B$ . For a given value of  $\phi_B$ , I define

$$\underline{A}_2(\phi_B) = \underline{P}_c q_{B1}^* - c_B(q_{B1}^*) - [P_B q_B^* - c_B(q_B^*)]. \quad (15)$$

The expression on the right-hand side of (15) represents the increment in profit a brown seller could earn if it obtained the eco-label, relative to the unlabeled segment of the market. If the test cost is no larger than  $\phi_B \underline{A}_2(\phi_B)$ , then a pooling equilibrium obtains:<sup>7</sup> all sellers seek the eco-label. Here, the conditional probability a certified unit is green depends on the probability that a brown unit would pass the certification test,  $\phi_B$ . As with a separating equilibrium, there are parameter configurations under which net surplus is higher than in the no-information equilibrium; there are other configurations where welfare is lower.

As a trivial example of the first case, suppose the test is costless, and rarely passes brown units. Since the certified price is larger than the no-information equilibrium price, production of green units increases; this is welfare-enhancing. Production by brown sellers that obtain the eco-label is larger than in the no-information equilibrium, which lowers welfare, but these are rare. Brown sellers that do not receive the eco-label receive the price  $P_B$ , and hence produce the

socially optimal amount (where consumer value equals the firm's marginal cost). If  $\phi_B$  is sufficiently small, the effect from the latter group of brown sellers outweighs the effect from the former group of brown sellers, so a more desirable level of brown production occurs as well. With a costless test, then, net surplus would be higher with eco-labeling than in the no-information equilibrium.

However, there are parameter configurations consistent with a pooling equilibrium in which net surplus is lower. Suppose the test is costly, but only slightly informative, in the sense that  $\phi_B$  is close to one. In this event,  $\underline{\mu}$  is only slightly larger than  $\theta$ , and  $\underline{P}_c$  only slightly larger than  $P_0$ , the no-information equilibrium price. So long as test cost does not exceed  $\phi_B \underline{A}_2(\phi_B)$  sellers prefer to seek certification to directly entering the unlabeled segment of the market. But with price close to  $P_0$ , firms' expected profits are close to those earned in the no-information equilibrium; moreover, expected consumer surplus is nil, so welfare is measured by the sum of firms' expected profits. Accordingly, there is only a small gain in social surplus (gross of test costs), relative to the no-information equilibrium. It is easy to see that for  $\phi_B$  sufficiently close to one the test costs will outweigh any gains in social surplus, so that welfare falls. In this situation, the test is almost useless but costly, and firms are trapped into pursuing the eco-label because not doing so would mean accepting the low price. Again, the point is not so much that such an outcome is likely, but rather that there are configurations where eco-labeling is welfare-enhancing, and other combinations where it is deleterious. Notice too that, as in a separating equilibrium, in the context of a pooling equilibrium a sufficiently small increase in test cost lowers welfare.

Finally, suppose that  $\phi_B \underline{A}_2(\phi_B) < A < \phi_B \underline{A}_1$ . In this case, it cannot be an equilibrium for all brown sellers to pursue certification, nor can it be an equilibrium for all brown sellers to

eschew certification. The equilibrium configuration must instead have all brown sellers indifferent between pursuing the eco-label on the one hand, and placing their product in the unlabeled segment on the other hand. Accordingly,  $W_B = 0$ . At the same time, all green sellers strictly prefer to seek certification, since  $W_G > W_B$ . The indifference condition for brown sellers determines the equilibrium price paid to products with the eco-label; that price solves

$$P_c^e q_B^* - c_B(q_B^*) - [P_B q_B^* - c_B(q_B^*)] = A/\phi_B. \quad (16)$$

Notice that the optimal output  $q_B^*$  is itself a function of  $P_c^e$ . Then, based on eq. (8), the equilibrium certified price induces an equilibrium conditional probability that a randomly drawn certified unit is green; call this value  $\mu^e$ . Finally, a particular fraction of brown sellers that seek certification is determined via eq. (13). This equilibrium is partial-pooling: all green units and some brown units are certified, while the remaining brown units are unlabeled.<sup>8</sup>

As in the other two equilibrium classes, there are parameter configurations under which the introduction of an eco-labeling scheme leads to larger net social benefits than the no-information equilibrium, and other configurations where net social benefits are smaller. If the test is relatively weak, and relatively costly, then as in the discussion of pooling equilibrium net surplus can be lower than with eco-labeling. On the other hand, if the test passes brown units with low probability, and is relatively inexpensive, then as in the discussion of separating equilibrium net surplus can be larger than with eco-labeling. In any event, the benefits associated with a better alignment of production levels to consumer tastes must be compared against the aggregate test costs that deliver those benefits.

An interesting feature of this class of equilibrium, that does not appear in the other two classes of equilibria, is that increases in test cost are not unambiguously bad. Referring to eq. (16), an increase in  $A$  would force an increase in the certified price, so as to keep sellers of bad

units indifferent between seeking the eco-label and entering the untested segment of the market directly. But for consumers to be willing to pay a higher price, the conditional probability that a product with the eco-label is green must go up. In turn, this increase in conditional probability requires a smaller fraction of brown sellers attempt to masquerade as environmentally friendly firms. Two related results then follow. First, with the higher certified price, green sellers produce more. This is clearly socially attractive, in part because consumers value green products at a higher level than the certified price; increased green production then taps into some erstwhile foregone gains from trade. Second, the expected contribution of brown sellers to the pool of eco-labeled products falls; accordingly, the expected output of brown sellers must fall. Since consumers value such products at a lower level, this reduction eliminates some deadweight loss from excessive production of brown products (beyond the point where the marginal cost of producing a brown unit equals  $P_B$ ). Further, since green units are presumably associated with smaller externalities, total externalities are likely to be smaller with the larger test cost.

This observation raises an intriguing possibility: namely, that more precise but more expensive tests could be socially attractive, within the context of the partial pooling equilibria. A test that is less likely to pass brown units is surely socially attractive, but such a test seems likely to be more expensive. While that combination would not prove attractive in either a separating equilibrium or a pooling equilibrium, both effects could be welfare-enhancing in this context.

#### 4. Model 2: Brown units never pass

I now turn my attention to the scenario where the test is perfectly able to identify brown units and hence fails them, i.e.  $\phi_B = 0$ . With this assumption, it is immediate that  $\mu = 1$  (as long as some green units are tested), and hence  $P_c = P_G$ .

Since some green sellers are not certified, the unlabeled segment of the market contains some green and some brown units. Here, the key statistic is  $v$ , the conditional probability that an unlabeled unit is green. Suppose the fraction of green sellers that seek the eco-label as  $\lambda_G$ . From eq. (6), one then infers that

$$v = (1 - \phi_G \lambda_G) N_G q_G^* / [(1 - \phi_G \lambda_G) N_G q_G^* + N_B q_B^*]. \quad (17)$$

If no green sellers seek certification, so that  $\lambda_G = 0$ , then  $v = \theta$ , the probability a randomly drawn unit is green in the no-information equilibrium. If all green sellers pursue the eco-label, so that  $\lambda_B = 1$ , then  $v = \underline{\tilde{v}} \equiv (1 - \phi_G) N_G q_G^* / [(1 - \phi_G) N_G q_G^* + N_B q_B^*]$ . Write the unlabeled price consistent with this value as  $\tilde{P}_{un}$ , and the profits a green seller could obtain based on this price as  $\tilde{\pi}_G$ . Because the only certified products would be green, the certified price in the scenarios discussed below is  $P_G$ . The profits a certified green seller earns are

$$\bar{\pi}_G = P_G \bar{q}_G^* - c_G(\bar{q}_G^*). \quad (18)$$

As with model 1, there are parameter configurations supporting three types of equilibrium. Consider first the case where  $A \leq \phi_G [\bar{\pi}_G - \tilde{\pi}_G]$ , so that test costs do not exceed the expected increase in profit a green seller anticipates by seeking the eco-label. In this event there is a separating equilibrium, where only green sellers seek certification. In this variant of the model, only green units obtain the eco-label, and so the certified price equals the value consumers place on green units. As such, any certified green sellers produce the socially optimal output level. On the other hand, some green sellers will fail the test because  $\phi_G < 1$ ; any such sellers would then produce the output where their marginal cost equals the unlabeled price, which is smaller than the  $P_G$ . Further, since  $\phi_G$  is positive, the conditional probability an unlabeled unit is green must be smaller than the probability a randomly drawn unit in the no-

information equilibrium is green (i.e.,  $v < \theta$ ). Accordingly, the unlabeled price must be smaller than the no information equilibrium price. It follows that production of brown units is smaller in this equilibrium than in the no-information equilibrium. Depending on the magnitude of  $\phi_G$ , production of green sellers could either rise or fall, relative to the no-information equilibrium. For values of  $\phi_G$  is sufficiently close to one, production of green units will rise. Together with the reduced output of brown units, this contributes to an increase in net surplus; for small enough test costs, welfare is enhanced by the introduction of eco-labeling. On the other hand, if parameter combination of  $A$  and  $\phi_G$  is such that green sellers only slightly prefer testing, then both types of sellers are worse off in the separating equilibrium than in the no-information equilibrium, and hence the introduction of eco-labeling leads to a reduction in net surplus. This seems particularly plausible in the case where the test is very stringent, as some have advocated in practice.

Consider next the case where test costs are at least  $\bar{\pi}_G - \pi_{G0}$ . Here, there is a pooling equilibrium in which no sellers seek certification. In this event, as the certification process fails to deliver any information to the market, the no-information equilibrium results.

For intermediate values of the test cost, such  $\phi_G[\bar{\pi}_G - \tilde{\pi}_G] < A < \bar{\pi}_G - \pi_{G0}$ , a partial pooling equilibrium exists. In this equilibrium, a fraction  $\lambda_G$  of green sellers pursue the eco-label; green sellers are indifferent between having their products tested, and potentially obtaining the eco-label, or directly placing their products in the unlabeled segment of the market. Accordingly, the equilibrium unlabeled price sets  $W_G = 0$ :

$$P_G \bar{q}_G^* - c_G(\bar{q}_G^*) - [P_{un}^e q_G^{**} - c_G(q_G^{**})] = A/\phi_G. \quad (19)$$

Notice that the optimal output  $q_G^{**}$  is itself a function of  $P_{un}^e$ . Then, based on eq. (9), the equilibrium unlabeled price induces an equilibrium conditional probability that a randomly

drawn unlabeled unit is green; call this value  $v^e$ . Finally, a particular fraction of green sellers that seek certification is determined via eq. (17). As in the separating equilibrium discussed below,  $v^e < \theta$  and so the unlabeled price is smaller than the no-information price; it follows that production of brown units will fall. Also as with the separating equilibrium, the net effect on production by green sellers is ambiguous.

In contrast to the partial-pooling equilibrium in the context of model 1, this equilibrium is unambiguously worse than the no-information equilibrium. In both equilibria, expected consumer surplus is nil, so the welfare impact can be measured by firms' profits (taking test costs into account). Because  $v^e < \theta$ , it is clear that the equilibrium unlabeled price is smaller than the no-information equilibrium price; it follows that all who sell in the unlabeled segment are worse off than they were in the no-information equilibrium. But those green sellers who pursue certification are indifferent between having their products tested and directly entering the unlabeled market, so they too must be worse off. It follows that expected net surplus is smaller here than in the no-information equilibrium. Also in contrast to the class of partial-pooling equilibria in model 1, in the context of this model a small increase in test cost is unambiguously bad. In either model, such an increase would lead to a reduction in testing by those firms that were indifferent between seeking the eco-label and directly placing their products in the unlabeled segment. In model 1, those were brown sellers; as they produce too much in the no-information equilibrium the induced reduction in their output is to society's advantage. Here, the indifferent firms are green; as they produce too little in the no-information equilibrium the induced reduction in their output is deleterious.

5. Model 3: All products pass sometimes but not always

I now turn to the more complicated version where both types of sellers pass with positive probability that is less than one, i.e.  $0 < \phi_B < \phi_G < 1$ . One might argue that this version is the most empirically reasonable, in that it corresponds to a testing regime that is subject to both type I and type II errors. Indeed, in a number of countries where eco-labeling has been adopted there are proponents arguing that certification should involve rigorous standards. Some have even argued that the standards for the eco-label should be set so high that only a relatively small percentage of products are certified. In the context of my model, that translates into the stipulation that the test is sufficiently demanding that green sellers do not always pass. This could correspond to the model in the preceding section, or the model here, depending on the ability of the test to avoid false positives.

The extension of the earlier discussion is straightforward; here, one must allow for the possibility that each type of firm plays a mixed strategy, and adjust the calculation of the two key conditional probabilities accordingly. Writing the fraction of type  $k$  sellers that pursue certification as  $\lambda_k$ ,  $k = G$  or  $B$ , the adapted formulae are

$$\mu = \lambda_G \phi_G N_G q_G^* / (\lambda_G \phi_G N_G q_G^* + \lambda_B \phi_B N_B q_B^*), \quad (20)$$

$$v = (1 - \lambda_G \phi_G) N_G q_G^{**} / [(1 - \lambda_G \phi_G) N_G q_G^{**} + (1 - \lambda_B \phi_B) N_B q_B^{**}]; \quad (21)$$

and where I have retained the notation  $q_k^*$  (respectively,  $q_k^{**}$ ) as the output where marginal cost equals the certified (respectively, unlabeled) price for a type  $k$  firm.

It is easy to see that there are parameter combinations that would support a separating equilibrium, and other combinations that support a pooling equilibrium. In the first case, test costs that exceeded the potential gain in profit available to brown sellers, but that did not exceed the losses green sellers would suffer if they switched from testing to entering the unlabeled

segment directly would do. A separating equilibrium corresponds to  $\lambda_G = 1$ ,  $\lambda_B = 0$ . If such an equilibrium exists, then  $\mu = 1$ , and hence  $P_c = P_G$ ; write the value of  $v$  that results as  $\underline{v}$ , and the corresponding unlabeled price as  $\underline{P}_{un}$ . Inserting these two prices into eq. (12) yields the incremental values from testing,  $W_G$  and  $W_B$ . Since the former exceeds the latter, there are test costs that fall in between the two; for any such cost, a separating equilibrium obtains. Pooling could correspond to  $\lambda_G = 1$  and  $\lambda_B = 1$ , or to  $\lambda_G = 0$  and  $\lambda_B = 0$ . Analysis of these sub-cases is similar to the discussion in section 3 in the first instance, and section 4 in the second.

As in the earlier discussion, with intermediate values of test cost a partial pooling equilibrium can exist. Again, there are two possible versions. For sufficiently large test costs,  $W_G = 0 > W_B$ , in which case some green units are tested, and some are placed directly in the unlabeled segment, along with all brown units. This case is qualitatively similar to the case analyzed in section 4. For somewhat smaller test costs,  $W_G > 0 = W_B$ , in which case all green units, and some brown units, are tested, while some brown units placed directly in the unlabeled segment. This case is qualitatively similar to the case analyzed in section 3.

Because of the assumed cost homogeneity within each cohort, the motivations facing every green seller are the same; likewise, all brown sellers face the same incentives. As such, if one seller strictly prefers to have its product tested, all such sellers do; if one seller prefers to enter the unlabeled segment, so do all other sellers in that cost cohort. An intriguing possibility is that cost heterogeneity would eliminate this feature, allowing for the possibility that some but not all green sellers strictly preferred to pursue the eco-label, while some brown sellers strictly preferred to pursue certification. I sketch out such an extension in the next section.

6. Heterogeneous costs within each cohort

Suppose now that firms within a cohort have idiosyncratic costs. I assume that each firm's cost function is indexed by a parameter  $\alpha_{ki}$ , where the subscript  $k$  refers to the type of technology (G or B), and  $i$  refers to the firm. To parallel the discussion above, I assume costs take the form  $\alpha_{ki}c(q)$ . The firm's cost parameter is private information, but the industry distribution of each parameter is assumed to be common knowledge. Accordingly, all agents can calculate the equilibrium expected outputs of green and brown products, and the associated rational expectations prices. The probability distribution functions for cost parameters are  $f_B(\alpha_B)$  and  $f_G(\alpha_G)$ , with the associated cumulative distribution functions  $F_B(\alpha_B)$  and  $F_G(\alpha_G)$ , respectively. These probability distributions are defined on the intervals  $[\underline{\alpha}_k, \bar{\alpha}_k]$ ,  $k = B$  or  $G$ , where  $\underline{\alpha}_B \leq \underline{\alpha}_G$  and  $\bar{\alpha}_G \geq \bar{\alpha}_B$ . To capture the notion that it is generally more costly to use the green technology, all else equal, I assume that  $F_B$  first-order stochastically dominates  $F_G$ : for any  $\alpha$ ,  $F_B(\alpha) \geq F_G(\alpha)$ , with strict inequality arising when  $F_B > 0$  and  $F_G < 1$ . I maintain the assumption on pass probabilities from the preceding section, namely that  $1 > \phi_G > \phi_B > 0$ .

Each firm chooses its output level to maximize expected profits, based on its cost parameter and type, the price it will receive, and its decision as to pursue the eco-label or not. If the firm produces a positive level, it will be where price equals marginal cost:  $c'(q_{ki}^*) = P_k/\alpha_{ki}$ . If variable profits are negative at this level, however, the firm will opt to produce nothing. I denote firm  $i$ 's privately optimal output level, given that it is of type  $k$ , by  $q^*(P_k; \alpha_{ki})$ , where  $P_k$  is the price the firm anticipates receiving and  $\alpha_{ki}$  is the firm's cost parameter; this corresponds to the framework employed above. As before, if the firm has its product tested and passes, then  $P_k = P_c$ ; otherwise,  $P_k = P_{un}$ . In the following discussion, I will often refer to firm  $i$ 's optimal

outputs as  $q^*_{kic}$  if the product has received the eco-label and  $q^*_{kiu}$  if it has not. Accordingly, the expected payoff from testing is

$$\Pi_{ki}^* = \phi_k [P_c q^*_{kic} - \alpha_{ki} c(q^*_{kic})] + (1-\phi_k) [P_{un} q^*_{kiu} - \alpha_{ki} c(q^*_{kiu})] - A,$$

while the (certain) payoff from not testing equals

$$\pi_{ki}^* = P_{un} q^*_{kiu} - \alpha_{ki} c(q^*_{kiu}).$$

Again, these parallel the values described in the version of the model with homogeneous costs within a cohort.

The difference between these two payoffs depends on the probability of passing the test, the nature of costs, the cost parameter, and the test cost:

$$\begin{aligned} W_{ki} &= \Pi_{ki}^* - \pi_{ki}^* \\ &= \phi_k \{ [P_c q^*_{kic} - \alpha_{ki} c(q^*_{kic})] - [P_{un} q^*_{kiu} - \alpha_{ki} c(q^*_{kiu})] \} - A. \end{aligned} \quad (22)$$

All else equal, this difference is larger the *smaller* is the cost parameter. The intuition is immediate: such sellers have lower costs, and so are better able to take advantage of the higher price that obtains following certification. In turn, this implies that such sellers reap a larger gain from certification – it is worth more to them. Accordingly, for both types of sellers there is a cutoff value of the parameter such that all sellers of that type with smaller values (i.e., lower costs) strictly prefer to pursue the eco-label.

In equilibrium, prices are based on rational expectations, with underlying probabilities derived using Bayes' law. Calculation of equilibrium requires the determination of cutoff values of the cost parameters for green and brown sellers. At these cutoff values, the marginal seller is indifferent between participation in the two segments, i.e.  $W_{ki} = 0$ . Accordingly, the cutoff value for a type  $k$  seller is implicitly determined by the rule<sup>9</sup>

$$[P_c q^*_{kic} - \tilde{\alpha}_k c(q^*_{kic})] - [P_{un} q^*_{kiu} - \tilde{\alpha}_k c(q^*_{kiu})] = A/\phi_k. \quad (23)$$

The left-hand side of eq. (21) is the wedge between certified and uncertified profits. This wedge is easily seen to be decreasing in the cost parameter and  $P_{un}$ , and increasing in  $P_c$ . Because  $\phi_G > \phi_B$ , the right-hand side is smaller for green units. Accordingly, at the cutoff values, the wedge between certified and uncertified profits is smaller for green units, which suggests a greater incentive for green units to seek certification.

Type  $k$  sellers with  $\alpha_k \leq \tilde{\alpha}_k$  pursue certification, while those with  $\alpha_k > \tilde{\alpha}_k$  elect to enter the unlabeled segment. In terms of the notation from section 5, one can regard  $F_k(\tilde{\alpha}_k)$  as  $\lambda_k$ . Thus,  $N_{kt} = N_k F_k(\tilde{\alpha}_k)$  type  $k$  sellers that pursue certification, while  $N_k[1 - F_k(\tilde{\alpha}_k)]$  sellers prefer to enter the unlabeled segment of the market. Aggregate testing costs are thus  $A[N_{Gt} + N_{Bt}]$ .

To facilitate a description of the expected volumes of type  $k$  output in the certified and unlabeled segments, I define the function

$$\mathcal{F}_k(P, \alpha) = N_k \int_{\alpha_k}^{\alpha} f_k(a) q^*(P, a) da. \quad (24)$$

I note that  $\mathcal{F}_k(P, \alpha)$  is increasing in both  $P$  and  $\alpha$ . Moreover, because  $q_G^*(P, \alpha) = q_B^*(P, \alpha)$  for any  $P$  and  $\alpha$ , and because  $F_B$  first-order stochastically dominates  $F_G$ , it follows that  $\mathcal{F}_B(P, \alpha) > \mathcal{F}_G(P, \alpha)$  for any  $\alpha > \underline{\alpha}_B$ . In addition, all else equal, any increase in price induces a larger response from brown sellers, i.e.  $\partial \mathcal{F}_B(P, \alpha) / \partial P > \partial \mathcal{F}_G(P, \alpha) / \partial P$ .

Type  $k$  firms with  $\alpha_{ki} \leq \tilde{\alpha}_k$  pursue certification, acquiring the eco-label with probability  $\phi_k$ . The expected quantity of certified type  $k$  is then  $\phi_k \mathcal{F}_k(P_c, \tilde{\alpha}_k)$ ; the quantity of type  $k$  products

expected to wind up in the unlabeled segment of the market is  $\mathcal{F}_k(P_{un}, \bar{\alpha}_k) - \phi_k \mathcal{F}_k(P_{un}, \tilde{\alpha}_k)$ . All told, the anticipated quantity of type k units is

$$Q_k = \mathcal{F}_k(P_{un}, \bar{\alpha}_k) + \phi_k[\mathcal{F}_k(P_c, \tilde{\alpha}_k) - \mathcal{F}_k(P_{un}, \tilde{\alpha}_k)]. \quad (25)$$

Rational expectations prices are based on these quantities, using eqs. (5), (6), (8) and (9).

Assessing the impact of eco-labeling upon market quantities entails a comparison of these outputs to the outputs that would obtain in the no-information equilibrium. For type k sellers, aggregate output in the no-information market is

$$Q_k^0 = \mathcal{F}_k(P_0, \bar{\alpha}_k). \quad (26)$$

Comparing eqs. (25) and (26), the difference between aggregate output for type k sellers in the testing equilibrium and the no-information equilibrium,  $\Delta Q_k$ , is

$$\Delta Q_k = \mathcal{F}_k(P_{un}, \bar{\alpha}_k) - \mathcal{F}_k(P_0, \bar{\alpha}_k) + \phi_k[\mathcal{F}_k(P_c, \tilde{\alpha}_k) - \mathcal{F}_k(P_{un}, \tilde{\alpha}_k)]. \quad (27)$$

In equilibrium, one expects  $P_c > P_0 > P_{un}$ ; in this event, the first term is negative and the braced expression in the second term is positive, for both types of sellers. Given the comments above, both these impacts are larger in magnitude for brown sellers. As  $\phi_G > \phi_B$ , it follows that  $\Delta Q_G > \Delta Q_B$ . Accordingly, equilibrium in the testing market would have a larger fraction of green units than the no-information equilibrium. Even so, it is conceivable that aggregate production is greater for both types in the testing equilibrium; it is also conceivable that aggregate output falls for both types. This result is in contrast to the discussion with homogeneous costs in each cohort, wherein the testing equilibrium entailed larger green output, and smaller brown output, whenever the testing equilibrium differed from the no-information equilibrium.

Figure 1 illustrates the market with eco-labeling when firm's costs are idiosyncratic. Full-information prices are marked by the solid horizontal lines at  $P_G$  (for green) and  $P_B$  (for

brown). The no-information price is denoted by the solid horizontal line at  $P_0$ ; to avoid clutter I label this line on the right-hand side of the graph. The equilibrium price an unlabeled unit receives is shown by the dashed horizontal line  $P_{un}$ , while the equilibrium price paid to a product with the eco-label is indicated by the dashed horizontal line  $P_c$ . The plots  $S_{kc}$  may be used to determine the expected quantity of certified type  $k$  units; similarly, the lines  $S_{kun}$  show the expected volume of unlabeled type  $k$  units. If each cohort of sellers faces the same price, as in the no-information market, then the total amount of type  $k$  products supplied is given by the horizontal summation of the  $S_{kc}$  and  $S_{kun}$  lines, for both  $k = G$  and  $B$ . To evaluate the net impact of testing, I separately consider each of the four cohorts: unlabeled green units, certified green units, unlabeled brown units, and certified brown units. With the availability of the eco-label, production by sellers of unlabeled green units falls to  $Q_{Gun}$ , read off the  $S_{Gun}$  curve at  $P_{un}$ . This decrease in volume of green units induces a reduction in social surplus equal to the trapezoidal area I, between  $P_G$  and  $S_{Gun}$ , from the points of intersection of  $S_{Gun}$  with  $P_{un}$  and  $P_0$ . On the other hand, there is an increase of output from green sellers in the second cohort, those that obtain the eco-label. Output from this cohort increases to  $Q_{Gc}$ , read off the  $S_{Gc}$  curve at  $P_c$ . This increased output yields an increase in social surplus, by an amount equal to the trapezoidal area between  $P_G$  and  $S_{Gc}$ , from the points of intersection of  $S_{Gc}$  with  $P_c$  and  $P_0$ . I label this as area II. There are also two effects for sellers of brown units. Brown sellers whose products are not labeled reduce their output to  $Q_{Bun}$ , read off the  $S_{Bun}$  curve at  $P_{un}$ . As these units are priced above their value to consumers,  $P_B$ , this output reduction yields a welfare gain measured by the trapezoidal area III. Finally, brown sellers that acquire the eco-label increase their production to  $Q_{Bt}$ , read off the  $S_{Bt}$  curve at  $P_c$ . This increase in production exacerbates the over-production of brown units found in the original no-information equilibrium, lowering social surplus by an amount equal to the

trapezoidal area IV. The combined effect on social surplus is the sum of areas II and III, less areas I and IV. In this figure, it is apparent that the gains (areas II and III) dominate the losses (areas I and IV), so that the combined effect is to raise social surplus.

Even if the combined effects from introducing eco-labeling thus described led to an increase in social surplus, there is no guarantee that the combined effect would offset the aggregate testing cost. For example, with the parameters that this diagram is based on, the total test costs outweigh the combined increase in social surplus. In such an event, society would ultimately be worse off with eco-labeling.<sup>10</sup>

## 7. Discussion

Putting aside any production externalities associated with the two techniques, the socially efficient level of production for green (respectively, brown) products equates marginal cost with full-information price  $P_G$  (respectively,  $P_B$ ). In the original no-information equilibrium, it is apparent that an inefficiently large quantity of brown products is produced, and an inefficiently small amount of green products. Evidently, any change that lowers the quantity of brown units below  $Q_{B0}$  while raising the quantity of green units above  $Q_{G0}$  would reduce deadweight loss. But the combined impacts on the markets for green and brown products must be compared against aggregate test cost. It seems clear that the ultimate welfare implications depend upon the various attributes of the test, along with the supply elasticities for the two types of sellers. For the parameters upon which figures 1 and 2 are based, it turns out that eco-labeling yields a combined increase in social surplus, but that this effect is not large enough to offset the aggregate testing costs in the short run.

These welfare remarks focus on the market imperfection associated with asymmetric information. But there is an additional issue, namely that the brown technology is more likely to generate production externalities. This effect is not fully captured by a divergence between prices for green and brown units, which are more the result of consumer preferences than any explicit recognition of externalities. When firms are privately informed about production and abatement costs, as in the context of my model, environmental regulation is notoriously difficult. Whether society opts for a command-and-control approach, using standards, or a market-based approach, using effluent taxes or tradable permits, there is generally a welfare loss associated with the informational asymmetries. Appealing to outside interests, as with third party certification, to reduce the informational asymmetries therefore provides an intriguing alternative. Indeed, Tietenberg [1998] refers to this as the “third wave” of pollution control. The results I obtain above indicate that there can be welfare costs associated with third party certification, to the extent that welfare gains from improving information are smaller than the costs of providing that information. That being said, it is conceivable that the inclusion of an eco-labeling option with a more traditional form of environmental regulation would yield an outcome that is socially preferable to the second-best outcome typically found in models of environmental regulation. Identifying conditions where such an improvement could be expected to occur would have important implications for public policy towards environmental regulation.

While the presence of an eco-labeling option may be socially attractive under certain conditions, it is not likely that society would benefit by requiring firms to pursue certification. Such mandatory testing schemes have been suggested in a number of contexts of asymmetric information, including the Federal Trade Commission’s recent consideration of so-called lemons laws. Economists are generally unimpressed by such schemes, largely because of the belief that

it is better to let firms choose from self-interest. In both versions of my model, some brown sellers eschew testing. By requiring all sellers submit to the certification test, this outlet is eliminated; all firms must take the certification test or exit. Since profits from the unlabeled segment are strictly positive, these sellers are likely to remain in the market even if forced to pursue certification. But this influx of brown output into the cohort of tested units serves to depress both certified and unlabeled prices, which will lead to a reduction in green output. Worse, the difference between the certified and unlabeled prices would then tend to shrink, which in turn reduces the incentive for some sellers to select the green technology. Altogether, these effects serve to lower the percentage of green units in the market. For the set of parameters that Figure 2 is based on, the effect is so dramatic that green products disappear altogether; the result is a lemons market. In this case, the imposition of mandatory testing is ultimately self-defeating, in that it eliminates any motive for testing to occur at all.

While firms' technologies can sensibly be regarded as exogenous in a short run setting, one would ultimately want to allow firms to select the technology that seemed most profitable. Since testing is relatively disadvantageous to brown units, it seems plausible that some erstwhile brown firms would switch to the green technology. With this switch, the over-production of brown units and the under-production of green units would simultaneously be mitigated. Might it be the case that these combined effects are sufficiently large to outweigh the aggregate test costs? If so, the strength of the case to be made in favor of eco-labeling is likely to depend on the degree of flexibility firms possess in choosing production technologies, which in turn depends on the time frame one adopts.

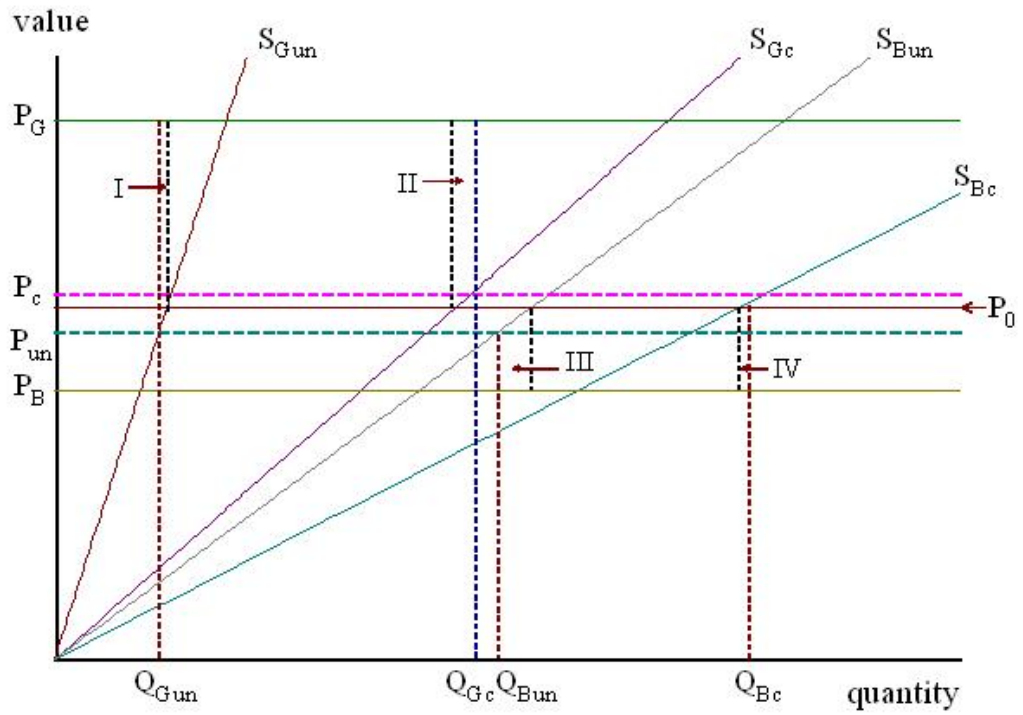
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Figure 1: Eco-labeling with heterogenous firms



## ENDNOTES

- 1 . For example, when the Dutch agency Stichting Milieukeur can not determine the absolute environmental effect of a particular product in a certain dimension, they “consider the matter in qualitative terms” (Giezman and Verhees, 1997, pg. 204).
2. The results in the model I am proposing differ substantially from the results in the context of a perfect (but costly) signal. There, the signal itself provides no useful information: all relevant information is conveyed by the identity of agents who purchase the signal (Stiglitz, 1975). The result is a first-best combination of green and brown outputs, with welfare gains that are typically larger than the aggregate signaling cost. In my model, since some brown firms succeed in obtaining certification, the net increase in social surplus from the signal is smaller, while aggregated signaling costs can be larger. On balance, the net effect on social surplus is less likely to be positive.
3. This precludes, for example, schemes where eco-labeled firms that are found to be brown are required to pay a penalty to the certifying company, as in the Canadian Environmental Choice Program (Wasik, 1996). For an analysis of a model with such fines, see Kirchhoff [2000].
4. As a practical matter, information on denied applications are generally unavailable (Vossenaar, 1997). Even if such information were available, if consumers believed that all failed units were brown, then any seller with a failed unit would (weakly) prefer the untested price. As a result, no units would be offered for sale at the failed price, so that Bayes’ rule could not be applied (Mason and Sterbenz, 1994). This awkwardness, which often arises in signaling games, could be resolved by applying a refinement such as Cho and Kreps [1987] Intuitive Criterion, or

one of Banks and Sobels' [1987] Divinity Criteria. In the present case, however, these refinements have no bite, so that the equilibrium I propose cannot be excluded. Whether consumers would be inclined to form such pessimistic expectations is of course an empirical matter. It is interesting to consider Indonesia's Public Disclosure program in this context. Under the Indonesian scheme, firms are assigned one of five color-coded factors, ranging from black (factories that have not attempted to control pollution and so cause serious damage) to gold (plants that are among the cleanest anywhere in the world). As reported in Table 1 of Tietenberg [1998], the vast majority of plants are in the 2<sup>nd</sup> or 3<sup>rd</sup> dirtiest category. One could then regard the 3<sup>rd</sup> dirtiest category as those that have passed the test and the 2<sup>nd</sup> dirtiest category as those that are unlabeled.

5. Since it is less costly to produce brown units than green units, it is clear that the profits available in the unlabeled segment are strictly greater for brown units. Accordingly, if the profits a certified green unit earns are at least as large as those earned by a brown unit,  $W_G > W_B$ . This restriction will hold, for example, if cost functions are of the form  $c_B(q) = \gamma q^\delta$  and  $c_G(q) = \alpha c_B(q)$  (i.e., iso-elastic), with  $\alpha \leq (1/\phi_B)^{\delta-1}$ . It is easy to show that maximal profit with such a cost function is  $v_B = (P^\delta / \delta \gamma)^{1/(\delta-1)} [1 - 1/\delta]$  for brown sellers, and  $v_G = v_B \alpha^{1/(1-\delta)}$  for green sellers. As the expected contribution to profits from testing is  $\phi_B v_B$  for brown sellers, and  $v_G$  for green sellers, the restriction on  $\alpha$  follows.

6. Expected consumer surplus is the weighted average of gains that would accrue if the unit purchased were green together with losses that would obtain if the unit were brown:  $\theta(P_G - P_0) + (1-\theta)(P_B - P_0)$ . Rearranging yields  $\theta P_G + (1-\theta)P_B - P_0$ , which equals zero by the definition of  $P_0$ .

7. The sense in which pooling occurs is related to the decision to seek certification; all sellers do so. Nevertheless, because some brown sellers will fail the test, some products are sold as unlabeled. By contrast, all green sellers are certified, since green products always pass the test. Accordingly, consumers know a product that is not labeled must be brown.

8. This configuration seems to be most consistent with actual experience. A number of critics of eco-labeling programs have complained that the labels are not “pure,” in the sense that some unworthy products seem to have obtained certification. While it is conceivable that such erroneous certification is the result of fraud on the part of sellers who obtain certification, and then purposely change their production scheme, it seems just as plausible that the certification test is subject to false positives, as in my model.

9. If  $V_G$  is non-negative at  $\bar{\alpha}_G$ , then  $\tilde{\alpha}_G = \bar{\alpha}_G$ : all green units are tested.

10. The diagram is based on the parameter values  $\underline{\alpha}_G = \underline{\alpha}_B = 1$ ,  $\bar{\alpha}_G = 2.5$ ,  $\bar{\alpha}_B = 2$ ,  $N_B = 2N_G$ ,  $P_G = 3$ ,  $P_B = 1.5$ ,  $\phi_G = .6$ ,  $\phi_B = .45$ ,  $A = .1$ , and  $\alpha_k$  uniformly distributed. From these parameter values, one may calculate the equilibrium cutoff values as  $\tilde{\alpha}_G = 2.0665$  and  $\tilde{\alpha}_B = 1.5283$ . The resultant equilibrium outputs are  $Q_G = 1.2664N_G$  and  $Q_B = 2.6565N_G$ , with rational expectations prices  $P_c = 2.1779$  and  $P_{un} = 1.8206$ . The no-information price is 1.9588, with outputs  $Q_{G0} = 1.1966N_G$  and  $Q_{B0} = 2.7155N_G$ . With the increase in output, deadweight loss from under-provision of green units is reduced by  $0.0712N_G$  and deadweight loss from over-provision of brown units is reduced by  $0.0247N_G$ . The combined test cost is  $0.1768N_G$ , so that net social surplus falls by  $0.0809N_G$ .

