On the Economics of Eco-Labeling

Charles F. Mason†
Department of Economics & Finance
University of Wyoming,
1000 E. University Ave.
Laramie, WY 82071

July 31, 2009

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, subject to both type I and type II errors, but where 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.

Keywords: Asymmetric Information; Eco-Labeling; Environmental Economics; Signaling; Testing

JEL Areas: Q2, D8, L15

†phone: +1-307-766-2178; fax: +1-307-766-5090; e-mail: bambuzlr@uwyo.edu

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 some consumers would be willing to pay a premium to "protect the environment" (Amacher et al., 2004; Bjorner et al., 2004; Cairncross, 1992; Cason and Gangadharan, 2001; Haji-Gazali and Simula, 1997; 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 levels of pollution 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 resulting from a more environmentally friendly process.

In the last decade or so, eco-labels have emerged in a wide range of countries (Karl and Orwatt, 2000; OECD, 1977; 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, 1977). 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.

Much of the existing literature that investigates eco-labels assumes perfect (as opposed to probabilistic) certification, either explicitly or implicitly.[1] While it is tempting to regard this certification as absolute, 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. While the certifying organization might wish to employ absolute standards, in practice this is not feasible.[2] The certifying party cannot be certain that the firm always uses an environmentally friendly technique, nor that the monitoring scheme is able to perfectly detect any violations. Furthermore, there is considerable doubt that the standards are perfectly correlated with "environmental friendliness" (Arda, 1997; Morris, 1997). These points noted, it seems reasonable to expect that that environmentally friendly firms would be more likely to obtain certification than environmentally unfriendly firms.

In my model of eco-labeling, I assume firms are either environmentally friendly (green) or not (brown), and that the certification process yields a positive report with some probability. While all firms must pay the same fee if they wish to pursue certification, green firms are more likely to pass the certification test than are brown firms. There are two issues of interest. First, what are the potential equilibria, and how are they related to the underlying parameter configurations? Second, how does the introduction of an eco-labeling option impact industry profits? The answer to the second question sheds light on the opportunity cost of eco-labeling, as an alternative to more traditional regulatory schemes. In particular, if eco-labeling raises industry profits then such an approach can be more efficient at reducing environmental externalities. 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). These comparative static effects can provide useful input into shaping a socially desirable eco-labeling scheme.

There are three classes of equilibria that might obtain, depending on the various parameters of the model. In discussing these classes, I highlight the parameter combinations that are required in order to support this outcome; the reader can make his or her own judgment as to the empirical relevance of such parameter combinations. The first class is a separating equilibrium: all green units are certified while no brown units are certified. This class is qualitatively equivalent to a regime where the eco-label perfectly identifies green products, as in much of the extant literature. The second class is a pooling equilibrium: all sellers take the same actions. There are two sub-classes here: one where all sellers pursue the eco-label, though some may fail to obtain certification, and one where no sellers pursue the eco-label (which is equivalent to the outcome when no labeling option exists, a regime I term "no information" in the pursuant discussion). The third class is a hybrid, wherein one class of sellers plays a pure strategy and the other plays a mixed strategy; I term this a "partial pooling" equilibrium. Here again there are two sub-classes: one where all green sellers seek certification, and some but not all brown sellers do; and one in which no brown seller seeks certification and some but not all green sellers do. The first sub-class is perhaps the most interesting and empirically relevant. It is somewhat related to problems where polluters are tempted to under-report emissions, a problem that has generated interest in the environmental regulation literature at least since Roberts and Spence (1976) and Kwerel (1977), and to problems involving environmental fraud (Hamilton and Zilberman, 2006). An interesting and counter-intuitive outcome of this sub-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.

Loosely speaking, these three possible configurations can be linked to the cost of certification. If certifying costs are moderately 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. For intermediate values of certifying costs, or for particularly large values, the equilibrium is partial pooling.

Putting aside any externalities associated with the two production techniques, the socially efficient level of production for green (respectively, brown) products equates supply with full-information price P_G (respectively, P_B). With perfectly elastic underlying demand, this combination also maximizes industry profits. In the no-information equilibrium, it is apparent that an inefficiently large quantity of brown products, and an inefficiently small quantity of green products, is produced. Evidently, any change that lowers the quantity of brown units while raising the quantity of green units would reduce deadweight loss and raise industry profits. In my model, 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 higher price, and brown sellers a lower price, than in the no-information equilibrium. But the test is costly, and so any putative gains from moving the volumes of green and brown units toward their first-best (full information) levels must be compared against aggregated testing costs.[3]

These remarks are tied to the market imperfection associated with asymmetric information. But there is, of course, a second market failure. As it is associated with larger environmental damages, the brown technology will generally cause larger production externalities. This second 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. That said, an eco-labeling regime can offer a useful policy tool if the reduction in production externalities associated with output rationalization comes at a low cost. Indeed, if the introduction of an eco-label raises industry profit this would reinforce the welfare gains associated with the reduction in environmental damages.

2 The Certifying Model

Consider a competitive market for a product that can either be produced using an environmentally friendly technology, or by a relatively dirty technology. Throughout the paper I will refer to the first type of product as "green," and to a seller with green products as a "green firm." Similarly, I refer to the second type of product as "brown," and to a seller with brown products as a "brown firm." All firms are either green or brown. There are consumers who would be willing to pay extra for green products, so that 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, each firm's supply curve is upward sloping, reflecting increasing marginal costs for each technique; this holds whether the firm is green or brown. I assume that all green firms have the same cost function $c_G(q)$ and that all brown firms have the same cost function $c_B(q)$. Because green production is more expensive, $c_G(q) > c_B(q)$ for any positive output q. For now, I assume that each firm's type is exogenously fixed; as I note below, this corresponds to a short-run focus. I explore the implications of relaxing this assumption later. [4]

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 $\alpha > 1$, $c_B{}'$ 0, and $c_B{}'' > 0$.[5] The value of α is assumed to be common knowledge. I assume there are no fixed costs [6] and that $\alpha c_B{}'(0) < P_B$, so that both types of firm produce in every equilibrium discussed below. [7]

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. 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. On the basis of this structure all agents can calculate the equilibrium expected outputs of green and brown products, and the associated rational expectations prices.

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 (P_G) and the price they would pay for a brown product (P_B) if they were perfectly informed regarding product type. If Q_G and Q_B are the quantities of green and brown products, respectively, available on the market, then the *ex ante* probability a randomly drawn unit is green would equal

$$\theta = Q_G/[Q_G + Q_B]. \tag{1}$$

The fraction θ is the weight placed on P_G described above, and so market price would be

$$P_0 = \theta P_G + (1-\theta)P_B. \tag{2}$$

In the pursuant discussion, I refer to the no-information equilibrium quantities as Q_{k0}, k = G or B. These quantities are identified from the supply curves for the two types of producer, based on the price P_0. Equivalently, they are determined by first finding the typical type k firm's output, and then multiplying by the number of firms. The individual firm quantities, q_{k0}, satisfy $c_B{}'(q_{B0}) = P_0 = c_G(q_{G0}) = \alpha c_B(q_{G0})$. Letting $\gamma(P)$ represent the inverse function to $c_B{}'(q)$, the no-information equilibrium price solves the equation[8]

$$P_0 = [N_G\gamma(P_0/\alpha)P_G + N_B\gamma(P_0)P_B] \,/\, [N_G\gamma(P_0/\alpha) + N_B\gamma(P_0)]\,. \tag{3}$$

For later reference, let π_{k0} denote the profits earned by a typical type k = G or B seller in the no-information equilibrium. I note that it is possible that $Q_{G0} = 0$, in which case $\pi_{G0} = 0$. For later reference, I note that expected consumer surplus in the no-information is nil. Net surplus can therefore be measured by industry profits.[9]

Now suppose that a third party offers to provide information about a firm's product, at a specified cost A. To this end, the third party employs a certification test. One can think of a test that involves the 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, or that some environmentally friendly firms could find certification impractical.[10] Alternatively, the test might involve the identification of some trait in the product or production process that is imperfectly correlated with environmental friendliness.[11] A test that is only imperfectly correlated with the product's "green-ness" could result in either false positives or false negatives. Even so, it stands to reason that the probability that a green firm would pass the test, ϕ_G, is larger than the probability that a brown firm would pass the test, ϕ_B. The probabilities of passing the test therefore satisfy the relations $1 \geq \phi_G > \phi_B > 0$. I assume that the cost of seeking certification is the same for both types of firms.[12]

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 its characterization as c, f or un. Under plausible conditions, consumer expectations would be such that failed units and untested units were lumped together as "unlabeled."[13] 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 certified green (brown) units is Q_{Gc} (Q_{Bc}). With these outputs, prior to observing any labels the *ex ante* probability that a randomly selected unit is green equals θ, as described by eq. (1). Associated with this probability is the *ex ante* expected price P_0, as given by eq. (2). Let the probability that a randomly selected unit is green, conditional on it being eco-labeled, be denoted as μ. Similarly, denote the probability that a randomly selected unit is green, conditional on it being unlabeled, by ν. Using Bayes' law, these posterior probabilities may be calculated as

$$\begin{aligned}\mu &= pr(G|c) = pr(c|G)\theta/pr(c),\\ \nu &= pr(G|un) = pr(un|G)\theta/pr(un),\end{aligned}$$

where $pr(c|G)$ is the probability that a unit will be certified, conditional on its seller being green, $pr(c)$ is the marginal probability of observing a certified unit, $pr(un|G)$ is the probability that a unit will be unlabeled, conditional on its seller being green, and $pr(un)$ is the marginal probability of observing an unlabeled unit. It is easy to see that $pr(c) = (Q_{Gc} + Q_{Bc})/(Q_G + Q_B)$ and that $pr(c|G) = Q_{Gc}/Q_G$. Consequently

$$\mu = Q_{Gc}/(Q_{Gc} + Q_{Bc}), \tag{4}$$

$$\nu = (Q_G - Q_{Gc})/(Q_G - Q_{Gc} + Q_B - Q_{Bc}). \tag{5}$$

Moreover, there are only two possibilities (a unit is either certified or it is unlabeled), so that $pr(un) = 1 - pr(c)$ and $pr(un|G)$ = 1 - $pr(c|G)$. Combined with eqs. (4) and (5), these remarks imply

$$\mu pr(c) + \nu[1 - pr(c)] = \theta. \tag{6}$$

The assumption that $\phi_G > \phi_B$ then implies $\mu > \nu$; as $pr(c) < 1$ it then follows that $\mu > \theta > \nu$.

To describe the equilibrium one must first determine the rational expectations prices. These prices are based on the conditional probabilities μ and ν according to:

$$P_c = \mu P_G + (1-\mu)P_B, \quad (7)$$

$$P_{un} = \nu P_G + (1-\nu)P_B. \quad (8)$$

Since $\mu > \theta > \nu$, 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 ($P_c > P_0 > P_{un}$). The information from the test is therefore useful, in the sense that it moves expected prices toward the full-information prices. Moreover, it can be shown that $\phi_G > pr(c)$.[14] The upshot is that the expected price for green firms who pursue the eco-label exceeds the no-information price. This increase in expected price will induce green firms to increase their production, so long as some green firms pursue certification (which is true in any equilibrium that differs from the no-information equilibrium).

At the same time, firms can condition their output on the actual price they will receive; whether this output rationalization effect induces an increase or a decrease in their expected output depends on the curvature of marginal costs. To see why this is so, consider the following thought experiment. Imagine a firm believes it will pass the certifying test with probability $pr(c)$, in which case it would receive price P_c and produce q_c; should it fail the test, it would receive price P_{un} and produce q_u. Based on these values, the firm expects to produce $q^e = pr(c)q_c + (1-pr(c))q_u$, and the expected value of the price it will receive is $P^e = pr(c)P_c + (1-pr(c))P_{un}$. In light of eq. (6) P^e equals the *ex ante* price. If marginal costs are linear, then expected output q^e with testing is the same as output at the *ex ante* price. But if marginal costs are concave, then by Jensen's inequality q^e is larger than the output at P^e. If instead marginal costs are convex, then q^e is smaller than the output at P^e. In light of these observations, allowing for non-linear marginal costs — as I do in this paper — will generate richer behavior than would obtain in a model with linear marginal costs.

Of course, firms would not believe the probability of passing the certifying test equaled $pr(c)$. In particular, green firms believe their chance of passing is larger; as such, the net effect is the combination of the two effects just discussed: The increase in expected price induces an increase in green firms' expected output, while the output rationalization can induce larger or smaller expected output levels. That noted, if marginal costs are weakly concave, or not 'too' convex, then introduction of an eco-label will lead each green firm to produce a larger expected output than in the no-information equilibrium. Such an increase in green production would be socially beneficial, both because green products are under-priced in the no-information equilibrium and because they are associated with lower environmental damages than are brown products. On the other hand, procuring the information associated with certification is costly, and these costs represent a reduction in net surplus. In addition, the increased green production pushes up the certified price, and may also increase the unlabeled price (depending on the exact nature of the equilibrium). But if the unlabeled price increases then brown production will also increase, which is unambiguously bad. Because the unlabeled price exceeds the value consumers place on brown output ($P_{un} > P_B$), anything that raises brown production lowers net surplus. In addition, an increase in brown output will raise the externality from the associated higher pollution levels. 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.

If the firm produces a positive output, then that output will equate marginal cost to the price the firm anticipates receiving; otherwise the firm will opt to produce nothing. If the firm has its product tested, and passes, then the firm anticipates receiving P_c; if it enters the untested segment, or if it fails the test, then it anticipates receiving $P_{un} = P_B$. In the pursuant discussion, I will to refer to the typical type k's optimal output as q_{k1} if the product has received the eco-label and q_{k2} if it has not. Let π_{k1} represent the profit a type k firms when it receives the price P_c and produces q_{k1}, and π_{k2} the profit a type k firms when it receives the price P_{un} and produces q_{k2}:

$$\begin{aligned}\pi_{k1} &= P_c\, q_{k1} - c_k(q_{k1}),\\ \pi_{k2} &= P_{un}\, q_{k2} - c_k(q_{k2}).\end{aligned}$$

The expected payoff from testing is

$$\begin{aligned}\Pi_k &= \phi_k\, \pi_{k1} + (1-\phi_k)\, \pi_{k2} - A\\ &= \pi_{k2} + \phi_k\, (\pi_{k1} - \pi_{k2}) - A,\end{aligned}$$

while the (certain) payoff from not testing equals π_{k2}.

The difference between the expected payoff from testing and the certain payoff from not testing 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:

$$\begin{aligned}W_k &= \Pi_k - \pi_{k2}\\ &= \phi_k\, \{[P_c\, q_{k1} - c_k(q_{k1}) - (P_{un}\, q_{k2} - c_k(q_{k2})\} - A. \qquad (9)\end{aligned}$$

Under plausible circumstances, $W_G > W_B$, so that green firms are more inclined to seek the eco-label than are brown firms.[15]

Assuming $W_G > W_B$, all green units pursue certification whenever any brown firms do so.

Write the equilibrium fraction of type k firms that seek the eco-label as λ_k; note that $\lambda_B = 0$ unless $\lambda_G = 1$. From eq. (4), one infers that

$$\mu = \phi_G \lambda_G N_G q_{G1} / [\phi_G \lambda_G N_G q_{G1} + \phi_B \lambda_B N_B q_{B1}]. \tag{10}$$

If no brown firms pursue certification, $\mu = 1$ and $P_c = P_G$. If all brown firms pursue the eco-label, so that $\lambda_B = 1$, then I write the value P_c takes as $\underline{P_c}$ and the value μ takes as $\underline{\mu}$. These two cases represent the extremes; if some, but not all, brown firms pursue certification, then μ lies between $\underline{\mu}$ and 1, while P_c lies between $\underline{P_c}$ and P_G.

Armed with the model described above one can investigate the various equilibrium configurations. These outcomes largely depend upon the cost of certification, A, and the two pass probabilities, ϕ_G and ϕ_B. I now turn to a discussion of these potential equilibria.

3 Separating Equilibrium

I start my discussion of the various types of equilibrium by investigating conditions that generate a separating equilibrium — a class of equilibrium that has received considerable attention in the literature. In the separating equilibrium, all green firms and no brown firms pursue certification, and so $\mu = 1$ and $P_c = P_G$. This outcome is qualitatively identical to the regime one would observe were certification noiseless in the sense that only green firms would obtain the eco-label.

Since $\alpha c_B'(0) < P_B \leq P_{un}$ any green firm that failed to obtain the eco-label would still be willing to participate in the unlabeled market. A description of conditions underlying this class of equilibrium is therefore linked to the equilibrium within the unlabeled segment of the market. To derive the equilibrium unlabeled price, let $\hat{\nu}$ and $\hat{q}_k$ solve the two equations:

$$\hat{\nu} = (1-\phi_G)N_G\hat{q}_G \,/[(1-\phi_G)N_G\hat{q}_G + N_B\hat{q}_B], \tag{11}$$

$$c_k{}'(\hat{q}_k) = \hat{\nu}P_G + (1-\hat{\nu})P_B. \tag{12}$$

Notice that the right-hand side of eq. (12) is the value P_{un} takes when $\nu = \hat{\nu}$, so that $\hat{q}_k$ is the profit-maximizing output a type k firm would choose if it were selling in the unlabeled segment of the market. By writing down two versions of eq. (12), one for brown firms and one for green firms, and using eq. (11) to eliminate $\hat{\nu}$, one would obtain a system of two equations in the two unknowns $\hat{q}_B$ and $\hat{q}_G$. Inserting these two values into eq. (11) would then allow determination of P_{un}; for concreteness, I denote the resultant price as $\hat{P}_{un}$.

An alternative way of constructing this equilibrium price is to imagine a supply curve given by the horizontal summation of the brown firms' supply curve and the exogenous fraction $1-\phi_G$ of the green firms' supply curve. This supply curve gives the expected total amount offered for sale in the unlabeled segment of the market at any given price. Demand in this segment of the market is a bit more complex: it is a weighted sum of the two valuations P_G and P_B, with weights ν and $1-\nu$, respectively. Unlike the weight in the supply curve, these weights are endogenous. Since green firms would produce a positive amount at P_B, while brown firms would produce a positive amount at P_G, by continuity there exists a value of $\hat{\nu}$ and values $\hat{q}_k$ that solve eqs. (11) and (12).

Having determined the equilibrium price in the unlabeled segment of the market, I define

$$\hat{A}_1 = P_G \overline{q}_B - c_B(\overline{q}_B) - [\hat{P}_{un}\hat{q}_B - c_B(\hat{q}_B)], \quad (13)$$

$$\hat{\hat{A}}_1 = P_G \overline{q}_G - c_G(\overline{q}_G) - [\hat{P}_{un}\hat{q}_G - c_G(\hat{q}_G)]. \quad (14)$$

These values equal the gain from pursuing the eco-label, net of the test cost, with eq. (13) providing the relevant value for brown firms and eq. (14) providing the relevant value for green firms. Referring to eq. (9), for a separating equilibrium of this second sub-class to exist, the test cost must be at least as large as $\phi_B \hat{A}_1$ but no larger than $\phi_G \hat{\hat{A}}_1$. I summarize this description in:

Proposition 1 *Suppose that $\hat{\nu}$, $\hat{q}_G$ and $\hat{q}_B$ solve eqs. (11) and (12). If the test cost and pass parameters satisfy $\phi_B \hat{A}_1 \leq A \leq \phi_G \hat{\hat{A}}_1$, then a separating equilibrium exists in which all green firms and no brown firms seek the eco-label, and where any green firm that fails the certification test sells its product in the unlabeled segment of the market.*

Compared to the no-information equilibrium, green sellers produce a larger amount and brown sellers a smaller amount; both these effects are welfare-enhancing. However, the ultimate impact on net surplus is unclear. Since green firms would participate in the no-information equilibrium, they would earn positive profits there. The necessary condition for their participation in the separating equilibrium is that expected profits from pursuing the eco-label exceed the certain profits available in the unlabeled segment of the market. But these latter profits are plainly smaller than the profits green firms would earn in the no-information equilibrium, because the unlabeled price is smaller than the no-information price. Accordingly, if the test cost is sufficiently large then green firms' profits will be smaller in the separating equilibrium than in the no-information equilibrium. In particular, if $A = \phi_G \hat{\hat{A}}_1$ then green firms' expected profits are surely smaller than in the no-information equilibrium. Brown firms, on the other hand, are unambiguously worse off in the separating equilibrium (since $P_{un} < P_0$). Taken together, these remarks indicate that industry profits in the separating equilibrium can be smaller than in the no-information equilibrium. I summarize these remarks as:

Proposition 2 *If $\phi_B \hat{A}_1 \leq A \leq \phi_G \hat{\hat{A}}_1$, and A is sufficiently close to $\phi_G \hat{\hat{A}}_1$, then combined industry profits are smaller in the resultant separating equilibrium than in the no-information equilibrium.*

Proposition 1 indicates that a separating equilibrium can only exist if the probability brown firms can pass the certifying test is sufficiently small, relative to the test cost. If ϕ_B is not sufficiently small, or if A is not sufficiently large, there can be no separating equilibrium – though be other types of equilibrium can exist. I now turn to a discussion of one of those alternative equilibria: the pooling equilibrium.

4 Pooling Equilibrium

I next discuss a class of equilibria wherein all sellers seek the eco-label: $\lambda_G = \lambda_B = 1$. This is a pooling equilibrium with respect to the decision to seek certification — all sellers do so. As I noted above, this outcome yields the smallest possible equilibrium value for certified price, $\underline{P_c}$. Nevertheless, it can pay green firms to seek the eco-label in these conditions.

I first discuss the unlabeled segment. Let $\tilde{\nu}$ and $\tilde{q}_k$ solve the two equations:

$$\tilde{\nu} = (1-\phi_G)N_G\tilde{q}_G \,/[(1-\phi_G)N_G\tilde{q}_G + (1-\phi_B)N_B\tilde{q}_B], \tag{15}$$

$$c_k{}'(\tilde{q}_k) = \tilde{\nu} P_G + (1-\tilde{\nu}) P_B. \tag{16}$$

The right-hand side of eq. (16) is the value P_{un} takes when $\nu = \tilde{\nu}$, so that $\tilde{q}_k$ is the profit-maximizing output a type k firm would choose if it were selling in the unlabeled segment of the market. Using two versions of eq. (16), one for brown firms and one for green firms, and combining with eq. (15), one can solve for $\tilde{q}_B$ and $\tilde{q}_G$. Inserting these two values into eq. (15) then yields the equilibrium value in the unlabeled segment of the market, which I denote as $\tilde{P}_{un}$.

I next define

$$\hat{A}_2 = \underline{P_c}\, q_B^p - c_B(q_B^p) - [\tilde{P}_{un}\tilde{q}_B - c_B(\tilde{q}_B)]. \tag{17}$$

The expression on the right-hand side of eq. (17) represents the increment in profit a brown seller could earn if it obtained the eco-label, relative to the unlabeled segment of the market. I observe that $\hat{A}_2$ is strictly positive.

All sellers that are certified choose an output level that equates their marginal cost to the certified price. Based on these outputs, one may calculate the resultant conditional probability that a certified unit is green, $\underline{\mu}$; the certified price is then determined by eq. (7). Accordingly, the certified price in a pooling equilibrium is determined by solving the following system of equations:

$$c_k{}'(\tilde{q}_k) = \underline{P_c}, \quad \text{k = G, B}; \tag{18}$$

$$\underline{\mu} = \phi_G N_G \tilde{q}_G \,/\, (\phi_G N_G \tilde{q}_G + \phi_B N_B \tilde{q}_B)\,, \tag{19}$$

$$\underline{P_c} = \underline{\mu} P_G + (1-\underline{\mu}) P_B. \tag{20}$$

Note that $\underline{\mu}$, the conditional probability a certified unit is green, depends on the pass probabilities for both green and brown firms. As such, the certified price $\underline{P_c}$ itself depends on both ϕ_G and ϕ_B. In follows that $\hat{A}_2$ depends on both ϕ_G and ϕ_B. Since $\hat{A}_2 > 0$, there is a range of test costs that would support a pooling equilibrium so long as ϕ_B is positive.

Proposition 3 *If $A \leq \phi_B \hat{A}_2$, then a pooling equilibrium exists in which all firms seek the eco-label, and any firm that fails the certification test sells its product in the unlabeled segment of the market. The equilibrium price for all certified goods is $\underline{P_c}$, and the equilibrium price for all unlabeled goods is $\tilde{P}_{un}$.*

As in the first sub-class of separating equilibrium, green firms are unambiguously better off in the pooling equilibrium than in the no-information equilibrium if $\alpha c_B{}'(0) \geq P_B$. As in the earlier discussion, green firms that fail the certification test exit, but green firms that pass earn positive profits. On balance, the expected profits from taking the test exceed the test cost. Unlike the earlier discussion, brown firms are also at least as well off in the pooling equilibrium as they are in the no-information equilibrium. By construction, $\phi_B \underline{A}_2$ represents the expected gain from pursuing the eco-label. As Proposition 3 notes, the test cost is no larger than these expected gains in a pooling equilibrium; indeed, if these expected gains exceed the test cost then brown firms are strictly better off. As in the second sub-class of separating equilibrium, firms can be better or worse off in the pooling equilibrium if $\alpha c_B{}'(0) < P_B$.

An additional parallel between the outcomes in the pooling and separating equilibria relates to the impact of a marginal change in test cost or pass probabilities. Here too such marginal changes do not influence any firm's decision. Accordingly, an increase in test cost must strictly lower firms' expected profits.

Before proceeding to the discussion of the next class of equilibrium, I briefly discuss a second sub-class of pooling equilibrium in which all sellers eschew the eco-label. If the test is sufficiently costly, relative to ϕ_G, then $W_G < 0$. Since $W_G > W_B$ it would follow that no firm pursues the eco-label. This outcome is equivalent to the no-information equilibrium.

5 Partial Pooling Equilibrium

The preceding discussion showed that a separating equilibrium can exist if the test cost is sufficiently large, while a pooling equilibrium can exist if the test cost is sufficiently small. In the former case, only green firms seek the eco-label, while in the latter case all firms do so. One might argue that neither outcome is empirically plausible. If only green firms pursue certification there would be no concern about fraud. In fact, 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. 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, as some have argued is a non-trivial phenomenon. But it is also plausible that the certification test is subject to false positives. On the other hand, there seems to be little evidence to suggest all brown firms are attempting to obtain certification. These remarks suggest that a middle ground, in which the test cost is neither too large nor too small, might be empirically significant. I discuss the potential equilibrium configuration of such a middle ground in this section.

The first complication that must be addressed in this scenario is the possibility that either type of firm might play a mixed strategy. Recall that λ_k represents the probability that a typical type k = G or B firm will pursue the eco-label. These values can be interpreted as being induced by mixed strategies; they can also be interpreted as the expected fractions of type k firms that pursue certification. Let the equilibrium output selected by a certified type k firm be q_k^*, and let the equilibrium output selected by a type k firm that sells its product in the unlabeled segment of the market be q_k^{**}; these correspond to the values q_{k1} and q_{k2} described earlier, when evaluated at the partial pooling equilibrium prices. The conditional probability that a randomly drawn certified unit is green is given by eq. (10), upon substituting $q_{k1} = q_k^*$:

$$\mu^* = \lambda_G \phi_G N_G q_G^* / (\lambda_G \phi_G N_G q_G^* + \lambda_B \phi_B N_B q_B^*). \tag{21}$$

Likewise, the conditional probability that a randomly drawn unit from the unlabeled segment of the market is green is:

$$\nu^* = (1 - \lambda_G \phi_G) N_G q_G^{**} / [(1 - \lambda_G \phi_G) N_G q_G^{**} + (1 - \lambda_B \phi_B) N_B q_B^{**}]. \tag{22}$$

These conditional probabilities induce the equilibrium certified and unlabeled prices, as described by eqs. (7) and (8); call these prices P_c^* and P_{un}^*, respectively. The output a certified type k firm would produce sets its marginal cost equal to P_c^*:

$$c_k{}'(q_k^*) = P_c^*. \tag{23}$$

Likewise, the output an uncertified type k firm would produce would produce sets its marginal cost equal to P_{un}^*:[16]

$$c_k{}'(q_k^{**}) = P_{un}^*. \tag{24}$$

Based on these prices and outputs, one can also calculate W_k, the expected gain from pursuing the eco-label for a type k firm.

As $W_G > W_B$ there are two possible configurations in a partial pooling. In the first, $W_G > W_B = 0$ so that $\lambda_G = 1 > \lambda_B > 0$. In this sub-class of partial-pooling equilibrium all brown firms are indifferent between pursuing the eco-label on the one hand, or directly placing their product in the unlabeled segment on the other hand. The indifference condition for brown firm is

$$P_c^* q_B^* - c_B(q_B^*) - [P_{un}^* q_B^{**} - c_B(q_B^{**})] = A/\phi_B. \tag{25}$$

If $q_G^{**} = 0$ and $P_{un}^* = P_B$, the right-hand side of eq. (25) is independent of q_G^* and ϕ_G. In this scenario, the equilibrium certified price is uniquely determined by eq. (25). In turn, this induces a particular equilibrium value of μ, and thereby a particular equilibrium value of λ_B. If $\alpha c_B{}'(0) < P_B$, so that $q_G^{**} > 0$, matters are a bit more complicated. An equilibrium is then a combination of seven values: the four outputs q_k^* and q_k^{**}, two conditional probabilities μ^* and ν^*, and a value of λ_B, which solve the seven equations (21) – (25),[17] where the equilibrium prices are determined from μ^* and ν^* by eqs. (7) and (8), and where $\lambda_G = 1$. Notice that the outputs q_k^* are each a function of μ^*, while the outputs q_k^{**} are each a function of ν^*. By substituting these implicit functions into eqs. (21), (22) and (25), one could obtain a reduced-form system of three equations, the solution of which would produce the equilibrium values of μ^*, ν^* and λ_B. This is a partial-pooling equilibrium in the sense that there is some pooling (all green units and a fraction λ_B of brown pursue the eco-label) and some separation (the remaining fraction $1 - \lambda_B$ of brown units are directly placed in the unlabeled segment of the market). While deriving this equilibrium would seem to be a fairly complicated process, it turns out to be relatively simple to characterize.

Consider first the scenario where neither the no-information equilibrium nor the unlabeled segment of the market would contain some green products. Referring back to Proposition **??**, a separating equilibrium cannot exist if $A < \phi_B \underline{A}_1$. Proposition 3 shows that there cannot be a pooling equilibrium if $A > \phi_B \underline{A}_2$. As I noted above, $\underline{A}_1 > \underline{A}_2$. A partial-pooling equilibrium will then exist for parameter values such that

$$\phi_B \underline{A}_2 < A < \phi_B \underline{A}_1. \tag{26}$$

Consider next the scenario where $\alpha c_B{}'(0) < P_B$, so that both the no-information equilibrium and the unlabeled segment of the market would contain some green products. Referring back to Proposition 1, a separating equilibrium cannot exist if $A < \phi_B \hat{A}_1$. Proposition 3 shows that there cannot be a pooling equilibrium if $A > \phi_B \hat{A}_2$. As I noted above, $\hat{A}_1 > \hat{A}_2$. A partial-pooling equilibrium will then exist for parameter values such that

$$\phi_B \hat{A}_2 < A < \phi_B \hat{A}_1. \tag{27}$$

I summarize these points in the next Proposition:

Proposition 4 *If $\alpha c_B{}'(0) \geq P_B$ and $\phi_B \underline{A}_2 < A < \phi_B \underline{A}_1$, then a partial pooling equilibrium exists in which all green firms and a fraction λ_B of brown firms seek the eco-label, and where all brown firms but no green firms that fail the certification test sell their products in the unlabeled segment of the market at price P_B. If $\alpha c_B{}'(0) < P_B$ and $\phi_B \hat{A}_2 < A < \phi_B \hat{A}_1$, then a partial pooling equilibrium exists in which all firms seek the eco-label, and any firm that fails the certification test sells its product in the unlabeled segment of the market at price P^*_{un}.*

An interesting feature of this class of equilibrium, which does not appear in either the separating or pooling equilibria, is that increases in test cost can be socially beneficial. Referring to eq. (25), an increase in A would force an increase in the certified price, so as to keep green firms 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 certified product is green has to increase. In turn, this increase in conditional probability requires a smaller fraction of brown firms attempt to masquerade as environmentally friendly firms. Two related results then follow. First, with the higher certified price, green firms produce more, on average. This is clearly socially attractive, in part because consumers value green products at a higher level than the certified price; increased green production then mitigates some erstwhile deadweight loss. 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 firms are associated with smaller environmental damage than are brown firms, total externalities are likely to be smaller with the larger test cost.

The comparative static effects related to changes in the pass probabilities are also somewhat surprising. Consider first the sub-case where green firms do not participate in the unlabeled segment, so that the indifference condition for brown firms is found by replacing P_{un}^* with P_B in eq. (25). As I noted above, a small change in ϕ_G has no impact on the unlabeled price in this context; it follows that neither P_c^* nor λ_B will change either. By contrast, a small change in ϕ_B here raises the right-hand side of eq. (25); since the unlabeled price again remains fixed at P_B the only way for the indifference relation to be reinstated is for the certified price to increase. As with the increase in test costs discussed above, this is generally welfare-enhancing.

Consider next the sub-case where $\alpha c_B{}'(0) < P_B$. The comparative statics are more complex in this case. First, I note that either an increase in ϕ_G or a decrease in ϕ_B unambiguously lowers ν^*, which in turn causes a reduction in P_{un}^*. While at first blush this would seem to be a good thing, the indifference relation for brown firms then requires a compensating reduction in P_c^*. Thus one finds the surprising result that an increase in the probability that green firms pass the certifying test will lead to a *reduction* in the equilibrium price paid to certified units. By contrast, a reduction in ϕ_B has two effects: as in the first case discussed above, it raises the right-hand side of eq. (25). Here, however, there is a conflicting effect – it pushes P_{un}^* down. It is straightforward but tedious to see that the former effect dominates, so that the net effect is to induce an increase in P_c^*. The upshot is that, as with the first sub-case, the net effect on equilibrium prices from a marginal decrease in ϕ_B is larger than the effect from a marginal increase in ϕ_G.

These observations raise an intriguing possibility within the context of the partial pooling equilibrium. An adjustment to the certification test that results in fewer false positives will generally be socially attractive, even though 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 are welfare-enhancing in this context. I summarize these points in:

Proposition 5 *Starting from the first sub-class of partial pooling equilibrium, a marginal increase in the test cost or a marginal decrease in the probability that brown firms pass the certifying test are welfare-enhancing.*

As an interesting backdrop to this Proposition, I note that environmental groups often argue that certification should involve more rigorous standards. Indeed, 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, this view translates into the stipulation that the test should be so stringent that ϕ_G is relatively small (which would imply that ϕ_B is particularly small).

Since a tightening of standards that lowers ϕ_B will be welfare-enhancing, the argument for stricter standards would seem to have some merit within the context of a partial-pooling equilibrium.[18]

I conclude this section by briefly discussing a second potential partial-pooling equilibrium. For particularly large values of the test cost, it is conceivable that brown firms strictly prefer to not pursue the eco-label and that green firms are indifferent between pursuing the eco-label and directly entering the unlabeled segment of the market. In this scenario, there is a sub-class of partial-pooling equilibrium wherein a fraction $\lambda_G < 1$ of green firms and no brown firms pursue the eco-label. The equilibrium certified price then equals P_G and the unlabeled price sets $W_G = 0$:

$$P_G q_G^* - c_G(q_G^*) - [P_{un}^* q_G^{**} - c_G(q_G^{**})] = A/\phi_G. \tag{28}$$

Notice that the optimal output q_G^{**} is itself a function of P_{un}^*. Then, based on eq. (8), the equilibrium unlabeled price induces an equilibrium conditional probability that a randomly drawn unlabeled unit is green; call this value ν^*. Finally, noting that $\lambda_B = 0$, a particular fraction of green sellers that seek certification is determined via eq. (22). As I noted above, $\nu^* < \theta$ and so the unlabeled price is smaller than the no-information price. It follows that all firms that sell in the unlabeled segment are worse off than they would have been in the no-information equilibrium. But green firms are indifferent between having their products tested and directly entering the unlabeled market, so they must be worse off. It follows that expected net surplus is smaller here than in the no-information equilibrium.

6 Discussion

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. One interpretation of the results I obtain above is that any reduction in producer surplus that results from the introduction of third party certification should be compared against the costs attendant to other forms of environmental regulation, such as monitoring and enforcement costs. To the extent that producer surplus rises as a result of the improved information are smaller, that would suggest that eco-labeling presents an attractive alternative to other forms of regulatory control. 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 toward 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 the separating and partial-pooling equilibria, some brown firms eschew testing. By requiring all firms submit to the certification test, this outlet is eliminated; each firm must take the certification test or exit. Since profits from the unlabeled segment are strictly positive, it is not implausible that brown firms would 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. It is conceivable that the effect could be sufficiently dramatic that green products disappear altogether; the result would then be 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.

Because of the assumed cost homogeneity within each cohort, the motivations facing every green firm are the same; likewise, all brown firms face the same incentives. As such, if one green (brown) firm strictly prefers to have its product tested, all such firms do; if one seller prefers to enter the unlabeled segment, so do all other firms 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 firms strictly preferred to pursue the eco-label, while some brown firms strictly preferred to pursue certification.

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.

References

Akerlof, G. A. (1970). The market for lemons: Qualitative uncertainty and the market mechanism, *Quarterly Journal of Economics* **84**: 488–500.

Amacher, G. S., Koskela, E. and Ollikainen, M. (2004). Environmental quality competition and eco-labeling, *Journal of Environmental Economcis and Management* **47**: 284–306.

Arda, M. (1997). Environmentally preferable commodities, *in* S. Zarrilli, V. Jha and R. Vossenaar (eds), *Eco-Labelling and International Trade*, Macmillan Press, New York, N.Y.

Arora, S. and Cason, T. N. (1996). Why do firms volunteer to exceed environmental regulations? Understanding participation in EPA's 33/50 program, *Land Economics* **72**: 413–432.

Arora, S. and Cason, T. N. (1999). Do community characteristics influence environmental outcomes? Evidence from the Toxics Release Inventory, *Southern Economic Journal* **65**: 691–716.

Baksi, S. and Bose, P. (2006). Credence goods, efficient labelling policies, and regulatory enforcement, *Environmental and Resource Economics* **37**: 411–430.

Banks, J. S. and Sobel, J. (1987). Equilibrium selection in signaling games, *Econometrica* **55**: 647–661.

Bjorner, T. B., Hansen, L. G. and Russell, C. S. (2004). Environmental labeling and consumers choicean empirical analysis of the effect of the nordic swan, *Journal of Environmental Economics and Management* **47**: 411–434.

Cairncross, F. (1992). *Costing the Earth*, Harvard University Press, Cambridge, Mass.

Cason, T. N. and Gangadharan, L. (2001). Environmental labeling and incomplete consumer information in laboratory markets, *Journal of Environmental Economics and Management* **43**: 113–134.

Cho, I.-K. and Kreps, D. M. (1987). Signalling games and stable equilibria, *Quarterly Journal of Economics* **102**: 179–222.

Dosi, C. and Moretto, M. (2001). Is ecolabelling a reliable environmental policy measure?, *Environmental and Resource Economics* **18**: 113–127.

Giezman, I. and Verhees, F. (1997). Eco-labelling: Practical use of the cradle-to-grave approach, *in* S. Zarrilli, V. Jha and R. Vossenaar (eds), *Eco-Labelling and International Trade*, Macmillan Press, New York, N.Y.

Haji-Gazali, B. and Simula, M. (1997). Certification schemes for all timber and timber products, *in* S. Zarrilli, V. Jha and R. Vossenaar (eds), *Eco-Labelling and International Trade*, Macmillan Press, New York, N.Y.

Hamilton, S. F. and Zilberman, D. (2006). Green markets, eco-certification and equilibrium fraud, *Journal of Environmental Economics and Management* **52**: 627–644.

Ibanez, L. and Grolleau, G. (2008). Can ecolabeling schemes preserve the environment?, *Environmental and Resource Economics* **40**: 233–249.

Karl, H. and Orwatt, C. (2000). Economic aspects of environmental labelling, *in* T. Tietenberg (ed.), *International Yearbook of Environmental and Resource Economics*, Edward Elgar, Cheltenham, UK.

Kirchhoff, S. (2000). Green business and blue angels, *Environmental and Resource Economics* **15**: 403–420.

Konar, S. and Cohen, M. A. (1997). Information as regulation: The effect of community right to know laws on toxic emissions, *Journal of Environmental Economics and Management* **32**: 109–124.

Konar, S. and Cohen, M. A. (2001). Does the market value environmental performance?, *Review of Economics and Statistics* **83**: 281–289.

Kwerel, E. (1977). To tell the truth: Imperfect information and optimal pollution control, *Review of Economic Studies* **44**: 595–601.

Levin, G. (1990). Consumers turning green: JWT survey, *Advertising Age* **61**: 74.

Mason, C. F. (2006). An economic model of eco-labeling, *Environmental Modeling and Assessment* **11**: 131–143.

Mason, C. F. and Sterbenz, F. (1994). Imperfect product testing and market size, *International Economic Review* **35**: 61–85.

Mattoo, A. and Singh, H. V. (1994). Eco-labelling: Policy considerations, *Kyklos* **47**: 53–65.

Morris, J. (1997). *Green Goods? Consumers, Product Labels and the Environment*, IEA publications, London.

OECD (1977). Eco-labelling: Actual effects of selected programs. OECD Working Paper vol. 5, no. 44, Paris.

Roberts, M. J. and Spence, M. (1976). Effluent charges and licenses under uncertainty, *Journal of Public Economics* **5**: 193–208.

Robertson, P. (2003). Eco-labels and free riding. University of New South Wales Discussion Paper 2003/09.

Robertson, P. (2007). Global resources and eco-labels: a neutrality result, *Review of International Economics* **15**: 735–743.

Stiglitz, J. (1975). The theory of 'screening,' education, and the distribution of income, *American Economic Review* **65**: 283–300.

Swallow, S. and Sedjo, R. (2000). Eco-labelling consequences in general equilibrium: A graphical assessment, *Land Economics* **76**: 28–36.

Tietenberg, T. (1998). Disclosure strategies for pollution control, *Environmental and Resource Economics* **11**: 587–602.

Vossenaar, R. (1997). Eco-labelling and international trade: The main issues, *in* S. Zarrilli, V. Jha and R. Vossenaar (eds), *Eco-Labelling and International Trade*, Macmillan Press, New York, N.Y.

Wasik, J. F. (1996). *Green Marketing and Management: A Global Perspective*, Blackwell Publishers, Inc., Cambridge, MA.

Winterhalter, D. and Cassels, D. C. (1993). *United States Hardwood Forests: Consumer Perceptions and Willingness to Pay*, Purdue University Press, West Lafayette, IN.

Zhang, Z. and Assuncao, L. (2004). Domestic climate policies and the wto, *The World Economy* **27**: 359–386.

Notes

[1] Representative examples include Amacher et al. (2004); Baksi and Bose (2006); Karl and Orwatt (2000); Mattoo and Singh (1994); Robertson (2003, 2007); Swallow and Sedjo (2000). A small number of papers allow for probabilistic certification, at least in part of their analysis. Dosi and Moretto (2001) allow for the probability of obtaining an eco-label to be linked to the firm's stock of environmental capital, though they do not discuss how this linkage might manifest itself nor do they investigate the implications for market equilibrium. Hamilton and Zilberman (2006) do not explicitly allow for probabilistic certification, though they do consider a scenario where an auditor probabilistically investigates firms that claim to be green (e.g., by procuring an eco-label), where firms that are relatively greener are less likely to be 'caught' by the auditor. Ibanez and Grolleau (2008) analyze a three-stage duopoly game; in the first stage each firm chooses a production technology (e.g., brown or green), in stage 2 green firms decide whether or not to label their product, and in stage 3 consumers make purchase decisions. While their model has perfect identification of brown firms there is the possibility that some green firms will remain unlabeled. Mason (2006) considers a model with probabilistic certification but does not provide a detailed

description of the resultant equilibria.

[2] 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).

[3] The results in my model 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 can 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.

[4] Whether or not firms can adjust their technology over time, it is important that they can not do so immediately after observing the test result. For if such adjustments were possible all firms would be motivated to switch to the brown technology — since it is cheaper — rendering the ecolabel impotent.

[5] Mason (2006) provides an analysis using a simple linear-quadratic structure. The present paper extends this earlier analysis by allowing for arbitrary convex cost functions. As I note below, this is not just a cosmetic extension – it has important consequences for the impact of eco-labels on green production.

[6] While fixed costs could influence long run decisions regarding product style, the important issue in the context of my paper is that there are no avoidable fixed costs, i.e. that any fixed costs

must be paid whether or not the firm produces. Thus, incorporating fixed costs would not impact any of the decisions discussed in the paper; for expositional simplicity I abstract from fixed costs.

7 If $\alpha c_B{}'(0) \geq P_B$ then there are equilibrium configurations where only brown firms produce; such a regime would constitute a "market for lemons," as in the seminal Akerlof (1970) paper. Even if a lemons equilibrium exists there may be an equilibrium with positive production from higher-quality firms (Mason and Sterbenz, 1994), which correspond to green firms in the context of my model. Many of the features of the equilibria discussed below have similar counterparts in the case where $\alpha c_B{}'(0) \geq P_B$; details are available on request.

8 From eq. (1), $\theta = N_G \gamma(P_0/\alpha)/[N_G \gamma(P_0/\alpha) + N_B \gamma(P_0)]$; the expression in (3) then follows directly from (2). It is easy to see that the right side of (3) is increasing in P_0, and that it is strictly smaller than P_G when evaluated at $P_0 = P_G$. If $c_B(P_B/\alpha) < P_B$, so that green firms would produce at $P_0 = P_B$, then an equilibrium price larger than P_B and smaller than P_G exists. If $c_B(P_B/\alpha) \geq P_B$, a market for lemons obtains.

9 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. As consumer surplus is nil, net surplus is given by producer surplus.

10 A World Trade Organization case in the late 1990s found Brazilian textile producers had an unduly difficult time certifying that their products did not use pesticides (OECD, 1977).

11 This issue crops up anywhere there are environmental considerations at multiple stages in a product's life cycle, e.g. extraction of raw ingredients, production, packaging, consumption and

disposal (OECD, 1977). For example, paper products produced in a developing country might use virgin timber but a relatively clean production process while paper production in a developed country might use a greater amount of recycled paper but a less clean production process. While the ultimate environmental impact from these two approaches is open to debate, an eco-label might focus on the amount of recycled paper used. Other examples include energy efficiency and the recent Shrimp-Turtle dispute between the U.S. and various countries in south-eastern Asia; see Zhang and Assuncao (2004) for discussion.

[12] 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).

[13] As a practical matter, information on denied applications is 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 the Intuitive Criterion (Cho and Kreps, 1987) or one of the Divinity Criteria (Banks and Sobel, 1987). 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^{nd} or 3^{rd} dirtiest category. One could then regard the 3^{rd} dirtiest category as those that have passed the test and the 2^{nd} dirtiest category as those that are unlabeled.

14 Let λ_k denote the fraction of the N_k type k firms that pursue the eco-label and q_{k1} be the amount a certified type k firm will produce. Write $Q_{kt} = \lambda_k N_k q_{k1}$, so that $Q_{kc} = \phi_k Q_{kt}$. Then: $pr(c) = (Q_{Gc} + Q_{Bc})/(Q_G + Q_B) = (\phi_G Q_{Gt} + \phi_B Q_{Bt})/(Q_G + Q_B) < \phi_G(Q_{Gt} + Q_{Bt})/(Q_G + Q_B) < \phi_G$.

15 Since it is less costly to produce brown units than green units, is clear that the profits available in the unlabeled segment are strictly greater for brown firms. Accordingly, if the profits a certified green firm earns are at least as large as those earned by a certified brown firm, $W_G > W_B$; this does not seem a terribly restrictive assumption. It will hold, for example, if cost functions are of the form $c_B(q) = \beta q^\delta$ and $c_G(q) = \alpha c_B(q)$ (i.e., iso-elastic), with $\alpha, \delta > 1$. It is easy to show that maximal profit with such a cost function is $\pi_B = (1 - 1/\delta)[P^\delta/\delta\beta]^{(1/\delta - 1)}$ for brown sellers, and $\pi_G = \pi_B \alpha^{1/(1-\delta)}$ for green sellers. As α and δ both exceed 1 it follows that $\pi_G \geq \pi_B$, and hence $W_G > W_B$.

16 If type G firms earn negative profit at the output which solves eq. (24), then they will set $q_G^{**} = 0$; in this case the marginal condition in (24) will not hold.

17 There are two versions for each of eqs. (23) and (24), one for green firms and on for brown firms.

18 Weighing against this argument is the observation that a reduction in ϕ_G could be either welfare-enhancing or -reducing.