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Eco-Labeling and Market Equilibria with Noisy Certification Tests

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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, subject to both type I and type II errors, but where green firms more likely to pass than brown firms. While it commonly leads to an increase in the fraction of green units in the market, the introduction of an eco-label can either increase or decrease welfare.

Keywords Asymmetric information · Eco-labeling · Environmental economics · Signaling · Testing

JEL Classification Q5 · D8 · L15

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

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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 1997; 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 1997). 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.

Most papers in the existing literature that investigates eco-labels assume perfect (as opposed to probabilistic) certification, either explicitly or implicitly.[1] While it is tempting to regard 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. Though the certifying organization might wish to employ absolute standards, in practice such standards are unlikely to be realistic.[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. 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.

[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. Moreover, he focuses on linear marginal costs. As I show below, allowing for non-linear marginal costs can produce welfare effects of a significantly different magnitude.

[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).

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 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 sellers and no brown sellers pursue the eco-label. 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, where all sellers pursue the eco-label. 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. This 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 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. When no labeling option exists, a regime I term "no information" in the pursuant discussion, 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." 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; I consider the implications of allowing for downward-sloping demand in Sect. 6.1.

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. 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. For now, I assume 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 Sect. 6.2.[4]

[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.

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]

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

$$\theta = \frac{Q_G}{Q_G + Q_B}. \tag{1}$$

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 type k 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]

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

Let π_{k0} denote the profits earned by a typical type $k = G$ or B seller in the no-information equilibrium. For later reference, I note that expected consumer surplus in the no-information is nil, so that net surplus can be measured by industry profits.[9]

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[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.

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

[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 1997).

[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 1997). 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 US 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 2nd or 3rd dirtiest category. One could then regard the 3rd dirtiest category as those that have passed the test and the 2nd dirtiest category as those that are unlabeled.

$Q_{Gc}(Q_{Bc})$. 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

$$\mu = pr(G|c) = \frac{pr(c|G)}{pr(c)}\theta,$$
$$\nu = pr(G|un) = \frac{pr(un|G)}{pr(un)}\theta,$$

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

$$\mu = \frac{Q_{Gc}}{Q_{Gc} + Q_{Bc}}, \tag{4}$$
$$\nu = \frac{Q_G - Q_{Gc}}{Q_G - Q_{Gc} + Q_B - Q_{Bc}}. \tag{5}$$

There are only two possibilities: a unit is either certified or it is unlabeled; hence $pr(un) = 1 - pr(c)$ 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 $\phi_G > \phi_B$ 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:

$$P_c = \mu P_G + (1 - \mu)P_B, \tag{7}$$
$$P_{un} = \nu P_G + (1 - \nu)P_B. \tag{8}$$

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). In addition, the expected price for brown products will be less than the no-information price.

Because each firm can condition its output on the actual price it receives based on the test result, its expected output depends on the curvature of marginal costs. Consider the following thought experiment. Imagine a firm believes it will pass the certifying test with

[14] Let λ_k be the fraction of the N_k type k firms that pursue the eco-label, q_{kc} be the amount a certified type k firm will produce and $Q_{kt} = \lambda_k N_k q_{kc}$, $k = G$ or B. The expected amount of type k output in the certified segment is $Q_{kc} = \phi_k Q_{kt}$. Then $pr(c) = \frac{Q_{Gc}+Q_{Bc}}{Q_G+Q_B} = \frac{\phi_G Q_{Gt}+\phi_B Q_{Bt}}{Q_G+Q_B} < \phi_G(\frac{Q_{Gt}+Q_{Bt}}{Q_G+Q_B}) < \phi_G$.

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 the output that would be produced 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. Accordingly, 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 than $pr(c)$; this larger expected price further increases each green firm's expected output. On the other hand, the output rationalization effect just described 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. The effect on the unlabeled price depends on the exact nature of the equilibrium. Most commonly, the unlabeled price will be smaller than the no-information price, which is unambiguously good. Because the unlabeled price exceeds the value consumers place on brown output ($P_{un} > P_B$), anything that lowers brown production will raise net surplus. But if the unlabeled price increases then brown production will also increase, which would lower net surplus. Moreover, procuring the information associated with certification is costly, which reduces net surplus. In addition, an increase in brown output will exacerbate 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. 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_{kc} if the product has received the eco-label and q_{ku} if it has not. Let π_{kc} represent the profit a type $k = G$ or B firm earns when it receives the price P_c and produces q_{kc}, and denote the profit a type k firm earns when it receives the price P_{un} and produces q_{ku} by π_{ku}:

$$\pi_{kc} = P_c\, q_{kc} - c_k(q_{kc}), \tag{9}$$

$$\pi_{ku} = P_{un}\, q_{ku} - c_k(q_{ku}). \tag{10}$$

The expected payoff from testing is

$$\begin{aligned}\Pi_k &= \phi_k\, \pi_{kc} + (1 - \phi_k)\, \pi_{ku} - A \\ &= \pi_{ku} + \phi_k\, (\pi_{kc} - \pi_{ku}) - A,\end{aligned} \tag{11}$$

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

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:

$$\begin{aligned} W_k &= \Pi_k - \pi_{ku} \\ &= \phi_k \{[P_c\, q_{kc} - c_k(q_{kc}) - (P_{un}\, q_{ku} - c_k(q_{ku})\} - A. \end{aligned} \tag{12}$$

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

$$\mu = \phi_G \lambda_G N_G q_{Gc} / [\phi_G \lambda_G N_G q_{Gc} + \phi_B \lambda_B N_B q_{Bc}]. \tag{13}$$

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 $P_c = P_G$. To determine the unlabeled price let $\hat{\nu}$, $\hat{q}_G$ and $\hat{q}_B$ solve the following system of equations:

$$\hat{\nu} = (1 - \phi_G) N_G\, \hat{q}_G / [(1 - \phi_G) N_G\, \hat{q}_G + N_B\, \hat{q}_B], \tag{14}$$

$$c_G{}'(\hat{q}_G) = \hat{\nu} P_G + (1 - \hat{\nu}) P_B, \tag{15}$$

$$c_B{}'(\hat{q}_B) = \hat{\nu} P_G + (1 - \hat{\nu}) P_B. \tag{16}$$

The right-hand side of Eqs. (15) and (16) is the value P_{un} takes when $\nu = \hat{\nu}$, which I refer to below as $\hat{P}_{un}$. Thus, $\hat{q}_k$ is the profit-maximizing output a type k firm would choose if it were selling in the unlabeled segment of the market.

Now define

$$\hat{A}_1 = P_G\, \overline{q}_B - c_B(\overline{q}_B) - [\hat{P}_{un} \hat{q}_B - c_B(\hat{q}_B)], \tag{17}$$

$$\hat{\hat{A}}_1 = P_G\, \overline{q}_G - c_G(\overline{q}_G) - [\hat{P}_{un} \hat{q}_G - c_G(\hat{q}_G)]. \tag{18}$$

These values equal the gain from pursuing the eco-label, net of the test cost, with Eq. (17) providing the relevant value for brown firms and Eq. (18) providing the relevant value for green firms. Referring to Eq. (12), for a separating equilibrium 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 observation in:

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 is not a terribly restrictive assumption; I illustrate one sample—with iso-elastic cost functions, in the Appendix.

Proposition 1 *Suppose that* $\hat{\nu}$, $\hat{q}_G$ *and* $\hat{q}_B$ *solve Eqs.* (14), (15) *and* (16). *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 2 hints that increases in the test cost will lower profits from pursuing certification. Indeed, so long as $\phi_B \hat{A}_1 < A < \phi_G \hat{\hat{A}}_1$ then all green firms strictly prefer to pursue certification, while all brown firms strictly prefer to not pursue certification. Accordingly, a marginal change in test cost or either pass probability would not induce any firm to change its action, and hence would not alter the equilibrium outcome. An increase in the test cost therefore reduces green profits. Larger changes in these parameters, however, can yield a different equilibrium. In particular, if ϕ_B is sufficiently large, or if A is sufficiently small, there can be no separating equilibrium—though be other types of equilibrium can exist.

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.[16] 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.

Consider first the certified segment of the market. Let $\underline{\mu}$, $\tilde{q}_G$ and $\tilde{q}_B$ solve the equations:

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

$$c_G{}'(\tilde{q}_G) = \underline{\mu} P_G + (1 - \underline{\mu}) P_B, \tag{20}$$

[16] There is 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. As this outcome is equivalent to the no-information equilibrium, I do not discuss it further.

$$c_B{}'(\tilde{q}_B) = \underline{\mu} P_G + (1 - \underline{\mu}) P_B. \tag{21}$$

The right-hand side of Eqs. (20) and (21) is the value P_c takes when $\mu = \underline{\mu}$, which I refer to as $\underline{P_c}$ below. Thus, $\tilde{q}_k$ is the profit-maximizing output a type k firm would choose were it certified.

Consider next the unlabeled segment of the market. Let $\tilde{\nu}$, $\tilde{\tilde{q}}_G$ and $\tilde{\tilde{q}}_B$ solve the equations:

$$\tilde{\nu} = \frac{(1 - \phi_G) N_G \tilde{\tilde{q}}_G}{(1 - \phi_G) N_G \tilde{\tilde{q}}_G + (1 - \phi_B) N_B \tilde{\tilde{q}}_B}, \tag{22}$$

$$c_G{}'(\tilde{\tilde{q}}_G) = \tilde{\nu} P_G + (1 - \tilde{\nu}) P_B, \tag{23}$$

$$c_B{}'(\tilde{\tilde{q}}_B) = \tilde{\nu} P_G + (1 - \tilde{\nu}) P_B. \tag{24}$$

The right-hand side of Eqs. (23) and (24) is the value P_{un} takes when $\nu = \tilde{\nu}$, which I denote as $\tilde{P}_{un}$. Thus, $\tilde{\tilde{q}}_k$ is the profit-maximizing output a type $k = G$ or B firm would choose if it were selling in the unlabeled segment of the market.

I next define

$$\hat{A}_2 = \underline{P_c}\, \tilde{q}_B - c_B(\tilde{q}_B) - [\tilde{P}_{un} \tilde{\tilde{q}}_B - c_B(\tilde{\tilde{q}}_B)]. \tag{25}$$

The expression on the right-hand side of Eq. (25) 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. Referring back to Eq. (19), $\underline{\mu}$ depends on the pass probabilities for both green and brown firms; by extension, the certified price $\underline{P_c}$ does as well. But then $\hat{A}_2$ depends on both ϕ_G and ϕ_B; since $\hat{A}_2 > 0$, there is a range of test costs that support a pooling equilibrium:

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. Equilibrium prices are $\underline{P_c}$ for certified goods and $\tilde{P}_{un}$ for unlabeled goods.*

As in the separating equilibrium, green firms can be better or worse off in the pooling equilibrium than in the no-information equilibrium. Brown firms, on the other hand, are 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. Also as in the separating equilibrium, a marginal change in test cost or either pass probability does not influence any firm's decision in the pooling equilibrium, so an increase in the test cost must strictly lower all firms' expected profits.

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. 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 been certified. While such erroneous certification might be the result of fraud on the part of sellers who obtain certification, and then purposely change their production scheme, 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. Thus, a middle ground, in which the test cost is neither too large nor too small, seems likely to be empirically significant.

In such a scenario 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_{kc} and q_{ku} described earlier, when evaluated at the partial pooling equilibrium prices. The conditional probability that a randomly drawn certified unit is green is then given by Eq. (13), upon substituting $q_{kc} = q_k^*$:

$$\mu^* = \frac{\lambda_G\, \phi_G N_G q_G^*}{\lambda_G\, \phi_G N_G q_G^* + \lambda_B\, \phi_B N_B q_B^*}. \tag{26}$$

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

$$\nu^* = \frac{(1-\lambda_G\, \phi_G) N_G q_G^{**}}{(1-\lambda_G\, \phi_G) N_G q_G^{**} + (1-\lambda_B\, \phi_B) N_B q_B^{**}}. \tag{27}$$

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^*:

$$c_G{}'(q_G^*) = P_c^*, \tag{28}$$
$$c_B{}'(q_B^*) = P_c^*. \tag{29}$$

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

$$c_G{}'(q_G^{**}) = P_{un}^*, \tag{30}$$
$$c_B{}'(q_B^{**}) = P_{un}^*. \tag{31}$$

Based on these prices and outputs, one can 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 equilibrium. In the first, $W_G > W_B = 0$ so that $\lambda_G = 1 > \lambda_B > 0$. In the second, $0 = W_G > W_B$, so that $1 > \lambda_G > 0 = \lambda_B$. In the pursuant discussion I focus on the first sub-class of partial-pooling equilibrium,[17] where 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. This indifference implies

$$P_c^* q_B^* - c_B(q_B^*) - [P_{un}^* q_B^{**} - c_B(q_B^{**})] = A/\phi_B. \tag{32}$$

An equilibrium is then a combination of seven values: the four outputs q_k^* and q_k^{**} ($k = G, B$), two conditional probabilities μ^* and ν^*, and a value of λ_B, which solve the seven

[17] Details of this second equilibrium sub-class are available on request.

Eqs. (26)–(32), where the equilibrium prices are determined from μ^* and ν^* by Eqs. (7) and (8), and where $\lambda_G = 1$.

While deriving this equilibrium is fairly complicated, characterizing the equilibrium is relatively simple. Referring back to Proposition 1, a separating equilibrium cannot exist if $A < \phi_B \hat{A}_1$, while Proposition 3 shows that there cannot be a pooling equilibrium if $A > \phi_B \hat{A}_2$. Since $\hat{A}_1 > \hat{A}_2$, there is a range of test costs that support a partial-pooling equilibrium:

Proposition 4 *If $\phi_B \hat{A}_2 < A < \phi_B \hat{A}_1$, then a partial pooling equilibrium exists in which all green firms and some brown 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. (32), an increase in A would force an increase in the certified price, so as to keep brown 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. First, 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: it raises the right-hand side of Eq. (32), but it also pushes P^*_{un} down. It is straightforward but tedious to show that the first effect dominates, so that the net effect is to induce an increase in P^*_c. The upshot is that 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. I summarize these points in:

Proposition 5 *In a 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.*

Proposition 5 raises an intriguing possibility. 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

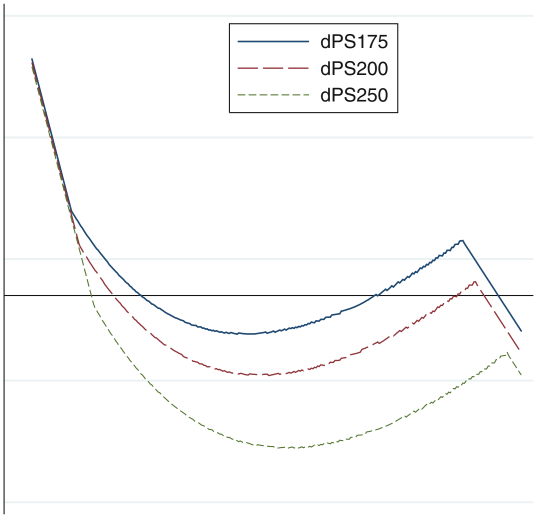

Fig. 1 Equilibrium welfare effects

in this context. In fact, 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]

The welfare implications of the three types of equilibria are summarized in Fig. 1. The figure is based on an example with iso-elastic costs, of the form $c_k(q_k) = \alpha_k q_k^\delta$ (whose details are presented in the Appendix); it graphs the difference between net surplus in the testing equilibrium and net surplus in the no-information equilibrium against test cost, for three levels of the cost elasticity parameter.[19] The solid curve, labeled dPS175, corresponds to a value of $\delta = 1.75$, which translates into a supply elasticity of $\frac{4}{3}$.[20] The long-dashed curve, labeled dPS200, corresponds to a value of $\delta = 2.00$ and a supply elasticity of 1 (and linear marginal costs). Finally, the short-dashed curve, labeled dPS250, corresponds to a value of $\delta = 2.50$ and a supply elasticity of $\frac{2}{3}$. There are a number of points of interest contained within this figure. First, the curves for each of the three elasticity values are linearly downward sloping at both small and large test cost levels. The former range corresponds to pooling equilibria, while the latter range corresponds to separating equilibria. As I noted above, in either type of equilibrium the configuration of outputs is independent of test cost, so increases in test cost simply subtract from net surplus. For intermediate values of the test cost, a partial pooling equilibrium obtains. Note here the curves are upward-sloping, corroborating Proposition 5. I note also that there is a range of test costs where net surplus

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

19 As noted above, in the version of the model consumer surplus is nil in all cases, and so net surplus corresponds to producer surplus. In the version of the model with downward-sloping demand net surplus also includes consumer surplus; see the discussion in Sect. 6.1.

20 As I show in the Appendix, the elasticity of supply for this example is $\eta = \frac{1}{\delta - 1}$.

is larger with testing than in the no-information equilibrium. This range is largely centered about small test costs, but there are other values that generate surplus gains. In addition, the largest loss in net surplus is relatively small in comparison to the no-information level, never exceeding 3% in this example. The last point to be made concerns the role of supply elasticity. The change in net surplus is greater for smaller values of δ, which correspond to more elastic supply, than it is for larger parameter values. This seems intuitive, as more elastic supply means firms (particularly green firms) are better able to capitalize on the higher price that certification delivers, and are therefore able to earn greater dividends from obtaining the eco-label.

6 Extensions

The analysis presented in the preceding sections is couched in terms of two assumptions one might take issue with: that demand for both types of products are perfectly elastic, and that firms can not change their type. I explore the implications of relaxing these assumptions in this section.

6.1 Downward-Sloping Demand

For products that trade on international markets, one can envision a situation under which the prices for green and brown units might truly be fixed within a local market. But in other situations it seems likely that the market demand curves for both green and brown units are downward-sloping. My model is readily extended to include downward-sloping demand, though at the cost of considerable extra complexity. In this sub-section I investigate this extension, and discuss the implications for the main results from above. As will become apparent, this extension does not qualitatively alter most of my results.

Denote the inverse demand curves for green and brown units as $P_G(Q)$ and $P_B(Q)$, respectively. If consumers expect an amount Q_k of type k product to be sold, the value they would then place on a type k unit, were it known to be such, would be

$$p_k = P_k(Q_k), \quad k = G \text{ or } B. \tag{33}$$

Within a given cohort ω of products, then, the price consumers would be willing to pay depends on their prediction of the probability of observing a green unit, ψ, as well as their predictions of the total number of type k units, $\hat{Q}_k$, $k = G, B$. That price would be

$$\hat{P}_\omega = \hat{p}_B + \psi(\hat{p}_G - \hat{p}_B), \tag{34}$$

where the prices $\hat{p}_k$ are determined by Eq. (33), based on $\hat{Q}_k$. This rule could apply for the no-information regime or for either the certified or unlabeled cohorts in the testing regime, if one substituted $\psi = \theta$, $\psi = \mu$, or $\psi = \nu$, respectively. Call the resultant prices $\hat{P}_0$, $\hat{P}_c$ and $\hat{P}_{un}$; these prices are directly analogous to the prices P_0, P_c and P_{un} derived above within the context of perfectly elastic demand.

Firms' decisions may be readily determined from the framework above by using these prices. For example, when an eco-label is available, a type k firm that is certified will produce $\hat{q}_k^*$, where $\hat{P}_c = c_k{}'(\hat{q}_k^*)$. These individual decisions lead to aggregate amounts, $\hat{Q}_k^*$. For the original consumer expectations to be consistent with a rational expectations equilibrium, the outputs firms would choose must lead to

$$\hat{Q}_k = \hat{Q}_k^*, \quad k = G \text{ or } B. \tag{35}$$

Equation (35) represents an additional pair of conditions that must be satisfied, in addition to the conditions that applied in the model with perfectly elastic demand. These new conditions are necessary because there are now two additional endogenous variables in any equilibrium, which derive from the downward-sloping demand curves. The new endogenous variables can be interpreted as prices $(\hat{p}_G, \hat{p}_B)$ or aggregate outputs $(\hat{Q}_G, \hat{Q}_B)$.

This additional complication notwithstanding, the qualitative nature of the equilibrium is much the same as above. As with perfectly elastic demands, there are parameter configurations supporting separating equilibria; other combinations support pooling equilibria; and still other combinations support partial pooling equilibria. Since there are parameters giving rise to the partial pooling equilibrium the comparative statics effects for that class carry over to the case of downward sloping demand. The conditions governing test cost are also similar to those discussed above, though the prices P_G and P_B would now have to be determined endogenously. As such, the relative importance of these equilibrium classes in the context of downward sloping demands will depend on the demand elasticities.

One important difference that emerges when one allows for downward-sloping demand is the appearance of consumer surplus. As such, consumers can benefit from the introduction of an eco-label, irrespective of the effect upon firms or upon net social surplus.

In the context of a testing equilibrium, expected consumer surplus is given by the area under the demand curve for green units, out to the total expected amount of green production (Q_{Gt}), plus the area under the brown demand curve, out to the total expected amount of brown production (Q_{Bt}), less total expected consumer expenditures. Total expenditures turn out to equal $P_G(Q_{Gt})Q_{Gt} + P_B(Q_{Bt})Q_{Bt}$,[21] so one can proceed with the calculation as if all type k units were sold at price $P_k(Q_{kt})$.

In the typical outcome, introduction of the eco-label will induce an increase in green production and a decrease in brown production. As such, consumer surplus attributable to green production will rise while consumer surplus attributable to brown production will fall. Without more information on the two demand curves it is impossible to sign the net effect; among other things this will depend upon the two demand elasticities.

To delve deeper into the net effect, I consider an example with constant demand elasticities (details of the example are contained in the Appendix). This framework allows relatively straightforward computation of consumer surplus, and hence net surplus. Using this framework, I calculated the equilibrium for nine combinations of demand and cost elasticities, including inelastic, unitary elastic and elastic values.[22]

Table 1 contains the results. Here I report the change in consumer surplus, producer surplus and net surplus as compared against the no-information equilibrium. Three interesting points emerge. First, all measures of change in surplus increase when the cost elasticity increases. This remark implies that the change in net surplus is smaller when marginal production costs are convex than when marginal production costs are linear. Second, all measures of change in surplus increase when the price elasticity of demand increases. The first two effects are both intuitive: since increases in either demand or supply elasticity suggest a more pronounced increase in green production following a switch from the no-information equilibrium to the testing equilibrium, one would expect sharper increases in consumer surplus. Moreover, such

[21] Let Q_{kc} represent the expected certified type k output; expected unlabeled type k output is then $Q_{ku} = Q_{kt} - Q_{kc}$, $k = G$ or B. For compactness, let $P_k = P_k(Q_{kt})$. With this notation, expected consumer expenditures are $P_c\,(Q_{Gc} + Q_{Bc}) + P_{un}\,(Q_{Gu} + Q_{Bu})$. Now, $P_c = P_B + \mu(P_G - P_B)$ and $P_{un} = P_B + \nu(P_G - P_B)$, where $\mu = \frac{Q_{Gc}}{Q_{Gc}+Q_{Bc}}$ and $\nu = \frac{Q_{Gu}}{Q_{Gu}+Q_{Bu}}$. Combining, expected consumer expenditures are $P_B\,(Q_{Gc} + Q_{Bc} + Q_{Gu} + Q_{Bu}) + (P_G - P_B)(Q_{Gc} + Q_{Gu}) = P_B\,Q_{Bt} + P_G\,Q_{Gt}$.

[22] This example is based on $\alpha = 1.05$, $A_B = 10$, $A_G = 11.5$, $\phi_G = .6$, $\phi_B = .3$, $A = .01$, $N_G = 20$ and $N_B = 30$.

Table 1 Welfare effects of supply and demand elasticity

Demand elasticity	Supply elasticity								
	2/3			1			4/3		
	ΔCS	ΔPS	ΔW	ΔCS	ΔPS	ΔW	ΔCS	ΔPS	ΔW
2/3	.0419	−.1148	−.0729	.0506	−.0816	−.0309	.0557	−.0639	−.0082
1	.0659	−.1021	−.0362	.0780	−.0763	.0018	.0885	−.0619	.0265
4/3	0.0915	−.0953	−.0038	.1068	−.0736	.0332	.1243	−.0613	.0630

a change seems likely to exert a significant effect on green firms profits. The results in Table 1 show that the positive impact on green firms' profits is important enough to yield a larger net impact on producer surplus. Even so, in all cases firms are collectively worse off in the testing equilibrium than in the no-information equilibrium.[23] This third effect stands in contrast to the earlier results, in the context of perfectly elastic demand, where firms generally are collectively better off in the testing equilibrium.

6.2 Endogenous Types

In a short-run setting, firms are either brown or green; they can not adjust their type. But what happens in a longer time frame? To answer this question, I adapt the earlier model by including a pre-stage, in which firms get to choose their type. To facilitate comparison with the earlier discussion I suppose the total number of firms remains fixed at N, but allow for N_G (the number of green firms) to vary. In this regard one can view each firm's decision as involving choices at three stages: they first choose their type; based on that choice they choose whether to have their products tested; then based on the test result they choose an output. Prior to the first choice, all firms are identical.

Because untested products sell at the unlabeled price, and because brown production is cheaper than green production, no firm that chooses to be green will then choose to not have their product tested. Firms that choose to be brown, on the other hand, might choose to be tested or not. It follows that there are three cohorts of potential interest: green and tested; brown and tested; brown and not tested. Consider first the outcome if no firm chooses the second or third cohort. In this case, all tested products must be green, and hence both the certified and unlabeled prices must equal P_G. But if a firm were to switch its type to Brown, it would realize the same price but bear lower costs; its profits would surely rise. Accordingly, it can not be an equilibrium for all firms to choose to be green. It can, on the other hand, be an equilibrium for all firms to be brown, but only if consumers hold dramatically pessimistic expectations regarding tested products. Since in the putative equilibrium no sellers are green, and since testing is costly, any brown seller would prefer the unlabeled segment of the market. But in that case there would be no products tested, and hence no data upon which to form expectations. It follows that no expectation is inconsistent with the data (an awkwardness that can arise in signaling games), so that particularly pessimistic expectations—such as the

[23] This result does not hold generically. Since firms are generally better off in the testing equilibrium when demand is perfectly elastic, they would be better off in the testing equilibrium when demand is very elastic. For example, with a demand elasticity of 8, and other parameters as in Table 1, shifting from the no-information equilibrium to the testing equilibrium raises producer surplus by.0016. The increase in producer surplus is even larger with more elastic demand: with an elasticity of 10, shifting from the no-information equilibrium to the testing equilibrium raises producer surplus by .0076.

prediction that any certified unit must be brown—cannot be ruled out by Bayes' law. But if one were to insist that consumers predicted passed units were more likely to be green than brown, the certified price would exceed the unlabeled price. If one conducted a thought experiment whereby this wedge was increased to ever-larger amounts, at a certain point it would pay some firms to deviate from the putative equilibrium, by choosing to be green.[24]

Since it can not be an equilibrium for all firms to elect to be green and an equilibrium where all firms are brown relies on consumers holding implausible expectations, and because all firms are *ex ante* identical, it follows that all firms must be indifferent between choosing to be green and choosing to be brown (based on the associated second-stage choices). Consider now the possibility that firms either choose to be green (and have their products tested) or to be brown (and eschew testing). Because this scheme has the feature that all tested products must be green, the certified price must surely be P_G; the unlabeled price would be less than P_G. This scenario has some similarities to the partial-pooling equilibrium discussed in the preceding section, though with an important difference. In that setting, the indifference relation forced expected profits with testing to equal certain profits from not testing, *conditional on the seller being brown*. Here, the indifference relation forces expected profits from testing for green sellers to equal certain profits from not testing for brown sellers; both exceed the expected profits from testing for brown sellers. Accordingly, this type of equilibrium can only obtain for sufficiently large test costs.

The second possibility would be for sellers to be indifferent between choosing to be green and choosing to be brown, with at least some brown sellers electing to have their products tested. While green sellers pass the test with greater probability, brown sellers have lower costs and hence would stand to earn larger profits, conditional on passing the test. For sellers to be indifferent between choosing to be green or brown, these two effects would have to exactly offset. This requirement imposes a constraint on the relation between μ, the conditional probabilities that a certified unit is green, and ν, the conditional probabilities that an unlabeled unit is green. In turn, this constraint induces a condition that pins down N_G. Referring back to Eqs. (9)–(11), the indifference relation can be written as

$$\begin{aligned}&\phi_G\,[P_c\,q_G^* - c_G(q_G^*)] - \phi_B\,[P_c\,q_B^* - c_B(q_B^*)]\\&\quad = (1-\phi_B)[P_{un}\,q_B^{**} - c_B(q_B^{**})] - (1-\phi_G)[P_{un}\,q_G^{**} - c_G(q_G^{**})].\end{aligned} \tag{36}$$

Equation (36) links P_c and P_{un}, and so induces a relation between μ and ν.

The probabilities μ and ν can also be calculated from Eqs. (26) and (27) as:

$$\mu = \frac{\phi_G N_G q_G^*}{\phi_G N_G q_G^* + \lambda\,\phi_B\,(N-N_G)q_B^*}, \tag{37}$$

$$\nu = \frac{(1-\phi_G)N_G q_G^{**}}{(1-\phi_G)N_G q_G^{**} + (1-\lambda\,\phi_B)(N-N_G)q_B^{**}}. \tag{38}$$

If sellers that choose to be brown prefer testing to not, then $\lambda = 1$; otherwise, $0 < \lambda < 1$. Note that both μ and ν are increasing in N_G. Since $\mu = \nu = 0$ when $N_G = 0$ and $\mu = \nu = 1$ when $N_G = N$, it follows that μ is concave in N_G and ν is convex in N_G; moreover, $\mu \geq \nu$, with strict inequality for values of N_G that are positive but less than N. Putting this all together, for a given value of N_G there is a unique relation $\mu(\nu)$ between the values of μ and ν that satisfy Eqs. (37) and (38).

[24] This argument is an application of the divinity criterion (Banks and Sobel 1987). An exception to this line of reasoning obtains when the test cost exceeds the difference between P_G and P_{un}, i.e. the test is so costly that no firm would ever be willing to pay it.

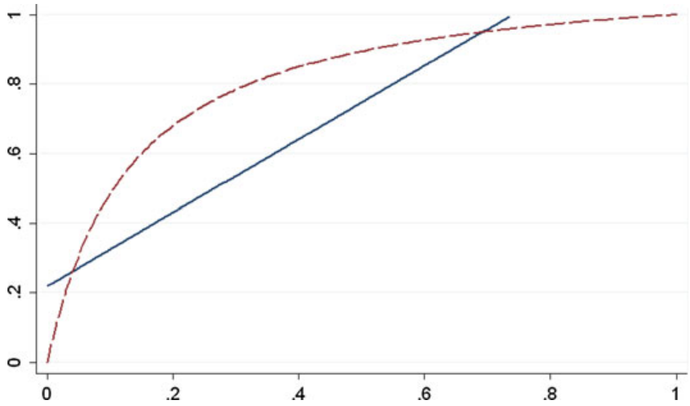

Fig. 2 Equilibrium with endogenous types

The equilibrium configuration must satisfy both Eq. (36) and the relation $\mu(\nu)$, as illustrated in Fig. 2. This graph uses the specific functional form discussed in the Appendix, with $\delta = 2$ and $\alpha = 1.05$; the assumed pass probabilities are $\phi_G = .6$ and $\phi_B = .3$; and the price premium for Green units is set at 15%. The solid line reflects combinations of μ and ν that satisfy Eq. (36), while the dashed curve represents the relation $\mu(\nu)$. The key point here is that there are three possible equilibria: a pessimistic equilibria (containing only brown units) and two equilibria with some brown and some green. Of these last two, the equilibrium with the smaller number of green units is unstable, in that a small decrease (respectively, increase) in the number of green units would create pressures that caused further decreases (respectively, increases) in the number of green units. By contrast, the equilibrium with the larger number of green units is stable.

By inverting the pair of equations induced by Eq. (36) and $\mu(\nu)$, one can determine the fraction of sellers that choose to be green from the equilibrium configuration of μ and ν. This fraction depends on the parameters of the certification test and the price premium consumers would be willing to pay for green products. Figure 3 illustrates the relation between the price premium and the fraction of sellers that choose to be green in the stable equilibrium. The premium consumers are willing to pay for green units is measured on the x-axis and the fraction of sellers that choose to be green is measured on the y-axis. Moving from left to right, the five curves show this relation for different values of ϕ_B, ranging from $\phi_B = .1$ (the curve labeled nG10) to $\phi_B = .3$ (the curve labeled nG30), in increments of .05. Two points are readily seen. First, for a given value of ϕ_B there is an increasing and concave relation between the price premium and the fraction of sellers that choose to be so. This relation is intuitive: higher price premiums make green more attractive, so increase the fraction of sellers that choose to be green; but as it is never an equilibrium for all sellers to be green, so increases in the price premium must render ever-smaller marginal additional increases in the number of green sellers. Second, increases in ϕ_B make green less attractive, so decrease the fraction of sellers that choose to be so. On the other hand, increases in ϕ_G will have the opposite effect to increases in ϕ_B, as they make it more attractive to be green.

Figure 4 explores the role played by the production cost. This figure uses comparable parameters to Table1; Fig. 3: $\alpha = 1.05, \phi_G = .6, \phi_B = .3$ and $A = .01$. As in Fig. 3, the premium consumers are willing to pay for green units is measured on the x-axis and the fraction of sellers that choose to be green is measured on the y-axis. The three curves

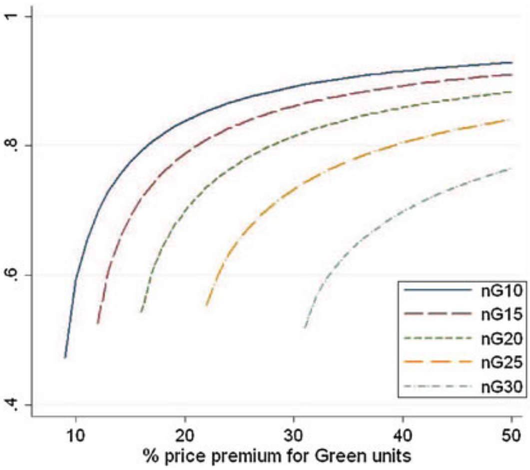

Fig. 3 Impact of changes in *Green* price premium

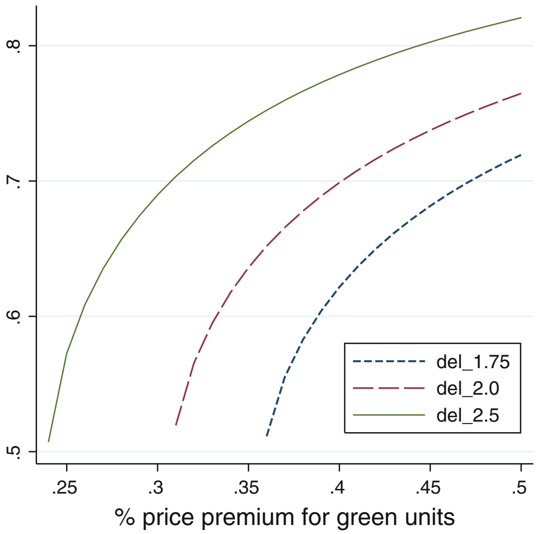

Fig. 4 Impact of cost elasticity

are based on three values of cost elasticity: the solid curve, labeled del_2.5, is based on a cost elasticity of $\frac{2}{3}$ (i.e., $\delta = 2.5$), the long-dashed curve, labeled del_2.0, is based on a cost elasticity of 1 (i.e., $\delta = 2.0$), and the short-dashed curve, labeled del_1.75, is based on a cost elasticity of $\frac{4}{3}$ (i.e., $\delta = 1.75$). Also as in Fig. 3, increases in the price premium raise the fraction of sellers that choose to be green; I note also that increases in the cost elasticity raise the fraction of sellers that choose to be green, all else equal. This observation corroborates the results in Table 1 (though in a slightly different setting).

The relationships described in Figs. 3 and 4 hold so long as the test cost is sufficiently small that sellers would strictly prefer testing to not, conditional on being Brown. For larger test costs the equilibrium must either be the first type I discussed in this subsection, or else it must be the case that sellers are indifferent between all three options.

7 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 net surplus (related to the information effects) resulting 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, or expected welfare losses attributable to asymmetric information. To the extent that net surplus rises as a result of the improved information, eco-labeling would be 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.

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 type $k = G$ or B firm strictly prefers to have its product tested, all type k firms do; if one type k seller prefers to enter the unlabeled segment, so do all other type k firms. An intriguing possibility is that cost heterogeneity would eliminate this feature. For example, one can imagine an outcome where some but not all green firms strictly preferred to pursue the eco-label, while some brown firms strictly preferred to pursue certification.

One might also wonder if firms that failed the certification test might be found out, and suffer additional losses resulting from the associated stigma. This phenomenon seems unlikely in the context of privately provided eco-labels, where the labeler might be reluctant to reveal the identity of failed sellers for fear of scaring away firms that might be potential customers of the certification service. By contrast, publicly provided eco-labels might be more inclined to reveal the identity of failed firms, as their objectives might have more to do with pleasing political constituency than making money. In a scheme where failed firms are identified, one imagines the expected payoff from pursuing certification would be reduced (as the payoff associated with failing the test would then be lower). Since this bad outcome is more likely to be borne by brown firms than by green firms, it might serve to push up expected payoffs to green sellers in a partial-pooling equilibrium. In turn, this would likely enhance the welfare effects associated with eco-labeling, further strengthening the case for its use as a substitute to more traditional regulatory approaches.

One potentially important application of my model regards carbon certification. As the importance of combating anthropogenic carbon emissions becomes ever more evident, there is an emerging interest in carbon certification programs.[25] While such certification schemes could yield important benefits, my analysis suggests a less optimistic view might be in order. Measuring carbon emissions has proven notoriously difficult, so it seems likely that identifying those firms that are "green" will also prove challenging. To the extent these schemes entail

[25] See Hamilton et al. (2009) and Wallis and Chalmers (2007) for discussion. Examples of carbon certification schemes include the Carbon Neutral Protocol (www.CarbonNeutral.com), the Gold Standard program (www.cdmgoldstandard.org) and the Green-E Climate Standard (http://www.green-e.org/).

noisy certification, there is no guarantee the introduction of a carbon certification program will facilitate large reductions in carbon emissions. That noted, improvements in verification methods, which roughly correspond to increasing the accuracy of the certification test, do seem likely to generate welfare gains. Devoting energy and resources toward identifying new technologies that yield those sort of improvements could be an important direction for research and development efforts in the near future.

Appendix: Details of Iso-Elastic Cost Example

In this appendix I describe the mechanics associated with an iso-elastic cost example. The example assumes $c_B(q) = q^\delta$ and $c_G(q) = \alpha\, c_B(q)$, with $\alpha, \delta > 1$. These cost functions induce marginal cost functions $c_B{}'(q) = \delta\, q^{\delta-1}$ and $c_G{}'(q) = \alpha\delta q^{\delta-1}$. At a price P, then, optimal outputs are

$$q_B = \left(\frac{P}{\delta}\right)^\eta, \tag{39}$$

$$q_G = \left(\frac{P}{\alpha\delta}\right)^\eta \equiv \alpha^{-\eta} q_B, \tag{40}$$

where $\eta = \frac{1}{(\delta-1)}$. Note that η is the firm's elasticity of supply; if all firms have the same cost elasticity function then η also represents the market supply elasticity. I note also that $\eta\delta = 1 + \eta$. Inserting the optimal output levels into the cost functions, straightforward algebraic manipulation yields maximized profits as

$$\pi_B = (\delta - 1)\left(\frac{P}{\delta}\right)^{1+\eta} \quad \text{for brown sellers,} \tag{41}$$

$$\pi_G = (\delta - 1)\alpha^{-\eta}\left(\frac{P}{\delta}\right)^{1+\eta} \quad \text{for green sellers.} \tag{42}$$

In light of Eq. (40), calculation of the key probabilities θ, μ and ν is particularly straightforward in this example. Referring back to Eq. (1), and noting that $Q_k = N_k q_k$, one has

$$\theta = \frac{N_G}{N_G + \alpha^\eta N_B}.$$

Similarly, it is straightforward to derive

$$\mu = \frac{\phi_G N_G}{\phi_G N_G + \alpha^\eta \lambda \phi_B N_B},$$

$$\nu = \frac{(1-\phi_G)N_G}{(1-\phi_G)N_G + \alpha^\eta(1-\lambda\phi_B)N_B}.$$

In the example with downward-sloping demand, I employed the specification $P_k(Q) = A_k Q^{-\kappa}$, where $\kappa = 1/\varepsilon$, the inverse of the demand elasticity. I assume $A_G > A_B$, which reflects the notion that the green demand curve lies above the brown demand curve. The introduction of the eco-label changes expected type k output from Q_{k0} in the no-information equilibrium to Q_{kt} in the testing equilibrium, and so the net effect on expected consumer surplus attributable to green products is

$$\Delta CS_G = \int_{Q_{G0}}^{Q_{Gt}} A_G Q^{-\kappa_G}\, \mathrm{d}G - [A_G Q_{Gt}^{-\kappa_G} Q_{Gt} - A_G Q_{G0}^{-\kappa_G} Q_{G0}]$$
$$= \left(\frac{A_G \kappa_G}{1-\kappa_G}\right)\left[Q_{Gt}^{1-\kappa_G} - Q_{G0}^{1-\kappa_G}\right],$$

assuming $\varepsilon_G \neq 1$. (If $\varepsilon_G = 1$ the integral yields $\ln(Q_{Gt}/Q_{G0})$, while the terms in the square bracket cancel out). Similarly, the expected change in consumer surplus attributable to brown products equals

$$\Delta CS_B = \left(\frac{A_B \kappa_B}{1-\kappa_B}\right)\left[Q_{B0}^{1-\kappa_B} - Q_{Bt}^{1-\kappa_B}\right].$$

Finally, in the example with an endogenously determined number of green firms, the key probabilities may be written as

$$\mu = \frac{\phi_G N_G}{\phi_G N_G + \alpha^{\eta} \lambda\, \phi_B\, (N - N_G)},$$
$$\nu = \frac{(1-\phi_G) N_G}{(1-\phi_G) N_G + \alpha^{\eta}(1-\lambda\, \phi_B)(N-N_G)}.$$

If sellers that choose to be brown prefer testing to not, then $\lambda = 1$; otherwise, $0 < \lambda < 1$. Both μ and ν will be increasing in N_G, as would be the normal case, so long as $\phi_G > \alpha^{\eta} \lambda\, \phi_B$, which is true for all parameter combinations in the simulations I report. Accordingly, there is a unique relation between the values of μ and ν that satisfy these equations for any given value of N_G:

$$\mu = \frac{\phi_G(1-\phi_B)}{\phi_G(1-\phi_B)\nu + \phi_B(1-\phi_G)(1-\nu)}\nu.$$

This relation corresponds to Eq. (36) in the text.

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