But What Does it Mean? Competition between Products Carrying Alternative Green Labels when Consumers are Active Acquirers of Information[*]

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Abstract

Programs that certify the environmental (or other social) attributes of firms are common. But the proliferation of labeling schemes makes it difficult for consumers to know what each one means – what level of 'greenness' does a particular label imply? We provide the first model in which consumers can expend effort to learn what labels mean. The relationship between information acquisition costs, firm pricing decisions, the market shares obtained by alternatively-labeled goods and a brown 'backstop' good, and total environmental impact prove complex. Consumer informedness can have perverse implications. In plausible cases a reduction in the cost of information *damages* environmental outcomes. Our results challenge the presumption that provision of environmental information to the public is necessarily good for welfare or the environment.

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1 Introduction

Environmental labeling schemes – certifying the performance of firms on a variety of environmental measures – have proliferated in recent years.[1] A number of analyses have sought to characterize the positive and normative implications of such certification (e.g., Mason, 2011; van't Veld and Kotchen, 2011; Fischer and Lyon, 2014; Heyes and Martin, 2017; Li and van't Veld, 2015; Ben Youssef and Abderrazak, 2009). The central assumptions of such analyses are (a) that there exist 'green' consumers – that at least a subset of consumers are willing to pay a premium for product with a lower environmental footprint – and (b) that those consumers understand what a particular label implies about the environmental performance of the supplying firm.

There is plenty of evidence to support the existence of green consumers and we do not dwell on that here.[2] Our focus is on the second assumption – that consumers know what labels mean. We show that a number of retained beliefs about the role of labels in competitive market settings are not robust to its relaxation. The approach that we take is consistent with the recent trend towards building increased behavioral realism into economic models across most sub-fields, in particular with regards to how boundedly rational agents acquire, process and react to information (see Caplin and Dean (2015), Chetty et al. (2009), Bernheim et al. (2018) for diverse examples).

If labels are to be effective they need to impact consumers' purchasing decisions. This in turn requires the recognition and comprehension of the label that a good displays, or fails to display. Much of the debate surrounding this point in practitioner circles has been on the ability of consumers to recognize and understand labels adequately. Consumer confusion about labels has been exacerbated as the number of overlapping labeling programs has proliferated, but as far back as 2002 the OECD (2002, p. 4) expressed concern over the growing number of eco-labels and the likelihood of consumer overload. The implications for trade have been echoed more recently in Prag et al (2015). This has not, however, been reflected in established economic models of certification, which assume that if a good carries a label then the representative consumer is able to (a) see, (b) recognize, and (c) understand the label, and adjust their purchasing behavior accordingly.[3]

The real world is very different – given how crowded the certification space is, this is hardly surprising. Consider Figure 1, which brings together a small sample of the green labels that might face an average North American consumer on a typical shopping trip. Even among a highly informed readership – such as reviewers of research about green labels at a leading academic journal

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[1] While we will talk about environmental labels it should be clear that the analysis applies to certification of a much wider set of otherwise difficult to discern social attributes (child labor and other labor practices, fairness of trade, etc.).

[2] See Roe et al. (2001), Teisl et al. (2002), Bjørner et al. (2004), Elfenbein and McManus (2010).

[3] The same applies to the small number of other models that are not explicitly about labeling but the provision of information about credence attributes of goods in conventional models of vertical quality differentiation (Cremer and Thisse (1999); Lerner and Tirole (2006); Farhi et al (2013)). There is a small experimental literature that attempts to get to grips with how consumers might interpret labeling claims. Cason and Gangadharan (2002), for example, find that cheap talk claims can sometimes generate a willingness to pay premium. Ippolito and Mathios (1990) also consider issues of how consumers interpret attribute information in the context of health claims on cereal packaging.

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– comprehension of the qualifying requirements for each label is likely to be fuzzy at best. While it is self-evident that the *OK Power* label refers in some way to energy use, what exactly does it imply? And how much better in that dimension is a product carrying such a label to an identical-looking one that does not? Or to one that carries the *GreenPower* label? Or one that carries the (perhaps) broader-based *Planet Positive* label?

Unsurprisingly, consumers are confused. This has been discussed in RESOLVE (2012), a forum that bought together leading researchers, business people, certifiers and policy experts in the area. The title of a 2014 article by the Guardian Newspaper in the UK decried "the 'Wild West' of eco-labels: sustainability claims are confusing consumers" (The Guardian, 4 July 2014). In referring to a 2013 Eurobarometer report, EU Environment Commissioner Janez Potočnik commented that "Of course we all want to see more green products on shelves, but this survey shows that most of us are confused by green claims... [t]hat's not good for consumers, and it is not rewarding those companies that are really making an effort." (European Commission, 2013).

A number of studies have sought to measure consumer *recognition* of various eco-labels. In 1996, 80% of West Germans and 56% of East Germans could recognize and name the Blue Label (OECD, 1997). In Denmark, 31% of respondents referred to the Nordic organic food label unaided, substantially higher than in other Nordic countries (Sweden 16%, Finland 5%). The unaided recall of the European Union's 'Flower' label was less than 2% in Sweden, though 18% in the Netherlands (Palm and Jarlboro, 1999).[4] Recognizing a label is not, of course, the same as understanding what it implies. In the United States, a 2014 survey by the Consumers Union revealed that 74% of respondents believed that the label 'organic' on the good implied that the product did not contain artificial ingredients (untrue), while 55% believed the same label applied to meat meant the animal spent at least some of its time outdoors (again, untrue) (Consumer Report, 2014). van Dam and Reuvekamp (1995) test Dutch consumers' interpretation of the labels that they had recognized. The fraction that they categorized as having an 'adequate' or better understanding of what the award of a label implied varied from 9% to 91%, depending on the label in question.

We develop a simple model that focuses on the competition between firms whose products carry distinct green labels. Those labels imply different levels of environmental performance – one 'high', one 'low' – but both strictly cleaner than a backstop 'brown' technology that is also available.[5]

Key to our analysis is that consumers are assumed not to know, at least initially, which label matches up to what level of environmental performance. Our model's central innovation lies in the explicit attention paid to providing plausible micro-foundations for the process whereby consumers acquire and interpret information about the meaning of a particular label—consumers are not passive here. As such our analysis complements other models of labels. In Brecard (2014) and

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[4]Recognizing a label when shown is not of course the same thing as unaided recall. Proactive rather than responsive awareness of existence may imply that a consumer is able to note the *absence* of a particular label on a product and update her evaluation of that product accordingly.

[5]We ignore here the possibility of fraudulent labels while acknowledging the potential importance of such fraud in some settings. Papers that study fraud include Hamilton and Zilberman (2006).

Figure 1: A sample of popular environmental labels. Source: EPA

Brecard (2017) competing products carry labels that are observationally distinct but consumers proceed on the assumption that the stringency of labeling criteria are equal across label types, even though they are not. In the model of consumer confusion by Harbaugh et al. (2011) consumers do not actively seek out information about the meaning of labels but update beliefs based on passive observation of the actions of others.[6]

In our model information acquisition is treated as an individual investment and the willingness of a consumer to incur the cost of becoming informed is determined endogenously.[7] The strategic choices facing firms are rendered more complex because they now have to market their products to a population of consumers that vary not just in the extent to which they are willing to pay a premium for products with green labels but also in their knowledge of what different labels mean. We acknowledge here the possibility that price may act as a signal of quality (following Milgrom and Roberts (1990), Bagwell and Riordan (1991)). However, in order to focus on the novelty of the paper – the active acquisition of costly information by consumers – we 'muffle' the role of prices in signaling quality. We assume that consumers will interpret a higher priced good to be of higher quality than a lower priced alternative, but only if the price differential is significantly large. In terms of inference about quality, small price differences will be ignored.

The model captures in a stylized way insights from marketing about how consumers respond to labels.[8] While existing models have dealt with issues of trust (e.g., Mahenc, 2016), fraud (e.g., Hamilton and Zilberman, 2006), selective disclosure (e.g., Lizzeri, 1999), and consumer confusion (e.g., Harbaugh et al., 2011), ours is the first model to allow consumers an active role in information acquisition, consistent with insights from marketing.[9] The structure of our model generates insights that have been overlooked in existing analysis on the role of information provision in environmental policy (through labels, disclosure requirements and other information-based programs). Informed consumers impose externalities—which can be positive or negative—on other consumers (informed and uninformed), on firms and on aggregate environmental outcomes.[10] Each time a consumer becomes informed, it affects the strategic pricing game played between firms carrying competing label types.

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[6]Our model also speaks to policy implications associated with public provision of information about labels' meaning, whereas Harbaugh et al. (2011) focus more on the managerial implications of consumer confusion.

[7]Uninformed consumers here are not the same as the myopic unaware consumers in Gabaix and Laibson (2006), but simply those who have not made the costly expenditure to learn the true meaning of the labels in question.

[8]Thøgersen (2002) provides a useful overview of the role that labels can play in influencing consumer behavior from a marketing perspective. An eco-label is regarded as an innovation in itself and "...innovation adoption theory describes the decision to buy such a product as a learning process, consisting of a number of successive phases, where the consumer obtains, accumulates, and integrates knowledge about the product and evaluates its self-relevance". He notes that the effort required on the part of consumers during this process: "...consumers have to go through an often time-consuming decision making process through which they first become aware of the label, and of labeled products, and then acquire sufficient knowledge to use it as a guide in decision making and to trust the message it conveys" (Thøgersen, 2002, p. 96).

[9]While not about labeling, Kennedy et al. (1994) examine the role of information provision and corrective taxes when consumers are imperfectly informed about the environmental footprint of a good.

[10]This interaction between firms and consumers also sets our analysis apart from, for example, Sallee (2014) where rational inattention is modeled in a pure discrete-choice framework.

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Our paper contributes to the emerging literature on green labels, in particular that part of the literature which allows for competition among labels (these include Heyes and Martin (2016), Li and van't Veld (2015), Fischer and Lyon (2014)). Our analysis relates to some of the wider literature on quality disclosure (for example, Board (2009), Fishman et al. (2003) and Grossman (1981); Dranove and Jin (2010) provide a survey). Since the seminal contribution of Stigler (1961), who focused on search, numerous authors have used theoretical and empirical methods to explore how consumers might learn about the existence of products, their prices and their characteristics (for examples, see Crawford and Shum (2005), De los Santos et al. (2012), Ellison and Ellison (2009), Goeree (2008)). Kihlstrom (1974) is an early example of a model in which consumers can acquire costly information about product quality. A separate strand explores alternative strategies that consumers might apply to purchase choices under uncertainty over product characteristics, for example using 'consideration sets' (Mehta et al. (2003)). The general theme in these models is that consumers trade off the benefits to increased informedness with the costs of additional search or information acquisition. Caplin and Dean (2015) develop a more general model of 'rational inattention' of economic agents. At an even broader level our analysis mirrors the trend of incorporating boundedly-rational agents into economic models.

An eye-catching implication of our model will be that taxing or constraining information availability can sometimes benefit market outcomes, and it is worth observing that we are not the first paper to generate such a possibility. Glaeser and Ujhelyi (2010) develop a model in which consumers perceive the true benefits of a product with error, and the size of that error is concavely increasing in how many dollars suppliers have spent on misinformation.[11] They show that while a monopolist will always produce too much misinformation, as the market becomes more competitive the amount of misinformation may by above or below the socially optimal level, such that more misinformation can in some circumstances be welfare-improving. Exploiting a different mechanism, Piccolo et al. (2015) show that false advertising can maximize consumer benefits in a duopoly in which firms have different product qualities. By not penalizing false advertising (by the low quality supplier) the planner can induce full pooling between the firms rather than full separation, putting downward pressure on prices by making firms appear undifferentiated in the eyes of consumers. In an insightful recent contribution Rhodes and Wilson (2018) model a setting in which firms use false advertising to overstate the value of their products, and develop precise conditions where policy optimally permits a positive level of false advertising. Sartzetakis et al. (2012) explore the optimal combination of a tax on the environmental footprint of a product and a program of information provision about its health characteristics, in a setting in which consumers internalize the latter (private) benefits of consumption, but not the former (public). Note that none of these speak directly to the sort of setting that we model in which (a) consumers actively acquire information about product characteristics, and (b) firms are not able to lie - to attach a label to their product they have to satisfy the requirement of the third party labelling organization - though they can

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[11]The consumer here will believe any claim, provided that the claim is backed by enough money. The process by which consumers form their beliefs is not made explicit.

exploit the fact that not all consumers understand the meaning of all third party labels.

In Section 2 we present the model and characterize its solution treating the cost of information acquisition as exogenous. In Section 3 we pay explicit attention to the role of that cost and investigate how varying it impacts aggregate environmental damage. In general the sign of that relationship is qualitatively ambiguous, and negative in plausible circumstances – information about what competing labels mean being more cheaply available could cause total environmental damage to be *higher*. While the main results are derived in a stylized setting, the point is really a more qualified one: if consumer confusion is unavoidable, then sometimes a marginal increase in the cost of information can be beneficial. This has non-standard implications for how we might think about public programs designed to reduce the difficulty of accessing such information. Section 4 discusses the robustness of our setting to alternative modeling assumptions. Section 5 concludes.

2   Model

We study an industry in which firms differ in the environmental standards to which they adhere and use eco-labels to certify their green credentials. For simplicity we assume three levels of environmental standards and two labels that are observationally distinct – with, say, different legends or logos. A label may denote high environmental stringency s_h or low stringency s_l, with $s_h > s_l > 0$. Consumers do not know (at least, initially) which label represents high standards and which denotes low standards. Products sold without an eco-label are known, or believed, to be 'brown', normalized here as embodying the lowest environmental standard $s_0 = 0$.[12]

Consumers are willing to pay for the greenness of products, but to different degrees. There is a continuum of consumers, each with unit demand for the good, deriving utility

$$u(s, p) = \theta s - p,$$

from paying price p for a good with environmental quality s. Here θ is a parameter that captures a consumer's willingness to pay for environmental quality, or simply their 'green premium'. We assume θ is distributed uniformly in an interval $[\underline{\theta}, \overline{\theta}]$, where $\underline{\theta} > 0$, and $\overline{\theta} = \underline{\theta} + 1$. We make the following assumptions on parameters.

Assumption 1 (A1)**.** *Consumers differ sufficiently in their green premium so that $\overline{\theta} \geq 2\underline{\theta}$.*

Assumption 2 (A2)**.** *Consumers attach sufficient value to environmental quality so that $\underline{\theta} > \frac{s_h - s_l}{2s_l}$.*

Assumption 1 says that there is sufficient heterogeneity in consumer tastes – the willingness to pay for the green attribute at the top end is at least double what it is at the bottom – and is

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[12]Labels of different stringency can come about from differences in certifiers' objectives (Fischer and Lyon, 2014). We do not model the process whereby certifiers design the stringency of their labels, rather we take stringency as given. A certifier can perfectly observe a firm's environmental performance, so that there can be no 'false-positives' or 'false-negatives' associated with certification. A firm cannot be awarded a label unless it meets the stringency demanded by the label (e.g., Fischer and Lyon, 2014; Heyes and Martin, 2017).

standard in models of vertical product differentiation (as in Tirole (1988, p. 296)). If we regard the ratio $(\overline{\theta}/\underline{\theta})$ as a measure of the heterogeneity of consumer preferences, the assumption puts a lower bound on this heterogeneity. Note, in passing, that given $\overline{\theta} = \underline{\theta} + 1$, the assumption also implies $\underline{\theta} \leq 1$.

Assumption 2 requires that we restrict attention to contexts in which consumers care 'enough' about the environment. If the consumers as a population attach very little or no weight to the environmental attribute then certification will have not traction. In particular, by putting a lower bound on the willingness to pay for quality, it ensures that for all consumers there is some price at which they would choose to buy a labeled product.

Together Assumptions 1 and 2 imply restrictions on parameters. Let $\bar{s} = 0.5(s_h + s_l)$ denote the average environmental quality of labeled products. Let $\sigma = (s_h - s_l)$ denote the difference between the quality levels of the high-label and low-label goods. It is easy to see that the two Assumptions 1 and 2 imply that $\bar{s} > \sigma$.[13] In other words, the difference in quality levels is less than their average.

Conventional analyses of vertically-differentiated firms focus on firms' competition in prices. In the simplest settings, there are two quality standards, say s_h and s_l. Consumers are assumed to know the quality offered by each firm, and buy from the firm that provides greater utility for any configuration of prices. The two firms compete for consumers, choosing positive prices p_h and p_l to maximize their profits.

In contrast, our model has three firms, associated with the three levels of environmental quality. Two firms carry distinct green labels that denote either a high environmental standard s_h or low standard s_l. The third sells an unlabeled or brown alternative which embodies no environmental enhancement (that is, embodying quality $s_0 = 0$). For expositional simplicity we assume that the marginal cost of production is zero, regardless of environmental quality. This is appealing analytically since it implies that nothing in our results will be driven by differences in firm costs.[14] Given consumer preferences, products that are unlabeled will sell only at a zero price. The firm supplying this brown product provides a backstop to consumers – the default dirty variant of the product to which the consumer reverts if none of the labeled alternatives succeed in attracting her custom.[15]

Our model make two other assumptions that depart from the conventional setting. First, consumers lack the knowledge to match the two labels to their environmental stringency, and have no alternative source of information that might help them to do so. Specifically, while the stringency levels s_h and s_l are common knowledge, consumers may not know which type of label is associated

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[13]Recall that Assumption 1 restricts $\theta \leq 1$, so the second assumption implies $s_h - s_l < 2s_l$. Adding $s_h - s_l$ to both sides we get $2\sigma < s_h + s_l$, which implies $\sigma < \bar{s}$.

[14]It also makes the the mapping from environmental outcomes to welfare outcomes straight-forward – when a consumer buys a cleaner good that is good for the environment, but at the same time good for welfare. For completeness, we explore the formulation with positive and heterogeneous marginal costs in a Supplementary Appendix.

[15]The supplier of the brown good is not modeled as an active player here. It supplies however as much of the backstop product as is demanded at price zero and makes zero profits. This role can equally be thought of as being played by a competitive fringe of many small sellers of unimproved products.

with stringency level s_l and which with s_h. This is the essence of consumers' potential confusion over labels. Our model will develop the possibility that some consumers might make costly effort to learn what labels mean.

Second, we assume that firms make their pricing decisions sequentially, with the high quality firm acting as leader in the price-setting game, and the low quality firm moving second. When making their choices consumers observe only the configuration of prices, not the sequence in which they were chosen, so are not able to infer quality from the sequence of pricing decisions.

To fix ideas we begin with the benchmark case with perfect information where all consumers are informed about the meaning of labels. We will then turn to the case where consumers are uninformed, to examine the role of learning.

2.1 Labels with perfect information

Suppose consumers are fully informed. In other words they can match labels to their true environmental quality and so know the true characteristics of each product on offer.

We model the interaction among the two labeled firms and consumers as a game, with the following sequence of moves.

1. The high quality firm chooses a price p_h.

2. The low quality firm observes p_h and chooses p_l in response.

3. Consumers make their purchasing decisions, picking the firm that gives them higher utility net of price.

The analysis here is straightforward. Consumers choose to buy from the firm that provides greater utility, $\theta s_h - p_h$ if they buy from the firm with high environmental standard, or $\theta s_l - p_l$ if they buy from the firm with low standard. Consumers whose utility is negative for both labeled firms at the posted prices fall back on the unlabeled product whose price is zero. The Appendix shows that

Proposition 1. *With perfect information about the quality represented by labels, equilibrium prices are given by*

$$p_h^* = \left(\frac{2\overline{\theta} - \underline{\theta}}{2} \right) \sigma \tag{1}$$

$$p_l^* = \left(\frac{2\overline{\theta} - 3\underline{\theta}}{4} \right) \sigma. \tag{2}$$

It is apparent (and expected) that $p_h^* > p_l^*$: the firm whose product carries the high-quality label sets a higher price. An interval of consumers with high willingness to pay for the environmental

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attribute buy the product bearing the high label, while those with lower willingness to pay buy the product bearing the low label.

At these equilibrium prices, quantities sold by the two labeled firms are

$$q_h^* = \left(\frac{2\overline{\theta} - \underline{\theta}}{4} \right) \tag{3}$$

$$q_l^* = \left(\frac{2\overline{\theta} - 3\underline{\theta}}{4} \right). \tag{4}$$

It is easy to check that the market is completely 'covered' by the two labeled firms: that is, each consumer buys from one of the two firms with labels, so $q_h^* + q_l^* = 1$.[16] The unlabeled firm's sales are $q_0^* = 0$.

The associated profits of the firms with labeled products are

$$\pi_h^* = \frac{1}{2} \left(\frac{2\overline{\theta} - \underline{\theta}}{2} \right)^2 \sigma \tag{5}$$

$$\pi_l^* = \left(\frac{2\overline{\theta} - 3\underline{\theta}}{4} \right)^2 \sigma. \tag{6}$$

In equilibrium the prices set by the firms imply that the high quality firm ends with greater share of the market and higher profits. As is standard for vertically-differentiated markets, equilibrium prices and profits are increasing in σ, the absolute difference between the values of the differentiating characteristic.[17]

2.2   Imperfect information and labels

We now study the interaction between firms under imperfect information. Specifically, while the two labels are observationally distinct, a consumer (initially at least) cannot tell which is which – which corresponds to the high level of environmental performance and which the low.

Consumers may choose to discover the meaning of labels by incurring costly effort. This may take the form of seeking out literature or visiting websites that carry information about the standards met to achieve the certification each label represents.

The extent of which any individual will be willing to become informed can be expected to depend upon: (1) the cost of information, in terms of the opportunity cost of time spent on research or the pecuniary cost in terms of subscription fees;[18] (2) the extent to which they value the environmental

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[16]The market is completely covered by labeled products as long as $p_l^* \leq \underline{\theta} s_l$. Here $p_l^* = \left(\frac{2\overline{\theta} - 3\underline{\theta}}{4} \right) \sigma = \left(\frac{2 - \underline{\theta}}{4} \right) \sigma$, so complete market coverage requires $\underline{\theta} \geq \frac{2\sigma}{\sigma + 4s_l}$. This holds from Assumption 2, which sets $\underline{\theta} \geq \frac{\sigma}{2s_l}$.

[17]Intuitively, price competition is more intense when product differentiation is low, eroding profits. In the limit the outcome converges to one of Bertrand competition, with zero profits.

[18]Policy interventions may be able to alter this costs: labeling authorities and others could lower this cost (for example, make websites easier to find and the information therein more accessible for a lay person to understand).

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attribute, and therefore the benefit to them of sorting out the characteristics of a product carrying one sort of label from another.

This second consideration is worth dwelling on in more detail. Depending upon what prices the consumer expects to see when they go to market, it may or may not be in the interest of a particular environmentally-conscious consumer to invest in disentangling the label types. This could be because even if the consumer knew which was which, prices are such that he would in any case opt for the brown/unlabeled backstop. But, more subtly, some consumers may be better off simply choosing a product carrying a label – any label – and accepting that there is a 50/50 chance it is either high or low.

We examine pricing decisions of firms when information is imperfect, and examine how these decisions vary with the cost of that information. Our previous setting is augmented as follows.

1. The two labels are observationally distinct (they "look" different) but consumers do not initially know which implies s_h and which implies s_l. Each consumer can discover this by incurring cost $k > 0$. The parameter k is common to all consumers and is common knowledge. Learning is perfect and private: consumers who incur cost learn the meaning of labels perfectly, but cannot communicate this finding to other consumers who choose to remain uninformed.

2. Firms set prices, with the high quality firm moving first, the low quality firm second.

3. Consumers use directly acquired information and, possibly, observed prices, to form beliefs about labels. Each consumer makes his purchasing decision based on these beliefs.

Information acquisition and beliefs

We start by analyzing the incentives for consumers to acquire information given prices expected to emerge in the subsequent pricing game as given.

Learning is costly but consumers are willing to incur this cost if it enables a better choice. The value of information lies in the extent to which it will improve a consumer's selection between products.

To fix ideas, begin with the case where both labeled firms charge the same price, $p > 0$. If a consumer is unable to distinguish between the stringency of the two labels, a randomly-picked labeled product embodies expected quality $\bar{s} = 0.5(s_h + s_l)$. Buying a labeled product at random, then, yields expected utility $\theta\bar{s} - p$ to a consumer of type θ. Incurring cost k allows this consumer to discover the meaning of the two labels, guiding the choice towards the higher quality product,

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NGOs and/or governments may adopt public education programs aimed at raising awareness of environmental impacts. See, for example, Feddersen and Gilligan (2001) for a model where an activist can provide information about the operating practices of a firm. As a real world example, the non-profit consumers' group ConsumerUnion runs the greenerchoices.org website that catalogs eco-labels and describes what a compliant firm must do to be awarded the label, with the goal of informing consumers.

with enhanced utility $\theta s_h - p$. If he anticipates that good carrying the distinct labels will sell at a common price p, a consumer will choose to become informed if and only if the informational gain exceeds the cost of being informed: that is, if

$$\theta(s_h - \bar{s}) \geq k,$$

or, equivalently, if $\theta \geq \frac{2k}{\sigma}$. It is evident that a consumer with a high green premium θ has a greater incentive to acquire information.

We introduce a minor adjustment in notation to aid our exposition. While k represents the direct cost of acquiring information, the denominator σ is a measure of the value of that information. When $\sigma = s_h - s_l$ is relatively small, the difference in the quality levels is low, implying lower informational gain. Higher values of σ amount to more valuable information. For sharper interpretation and to limit notation we define $\kappa = k/\sigma$ as the value-adjusted cost of information - in effect the cost per unit of information. As σ is a fixed parameter in our model, this is a simple normalization.

In terms of κ, therefore, if both labeled firms sell at a common price p only consumers with $\theta > 2\kappa$ will choose to acquire information. If information is sufficiently costly (i.e., if $\kappa > \frac{1}{2}\bar{\theta}$), no consumer will find it worthwhile to acquire information; if it is sufficiently cheap (if $\kappa < \frac{1}{2}\underline{\theta}$), all will become informed. For intermediate values of κ, the proportion who will choose to be informed is given as

$$\alpha(\kappa) = \bar{\theta} - 2\kappa. \tag{7}$$

Next consider configurations in which the two labeled firms charge different prices. Here we allow the possibility that even consumers who have not invested directly in information acquisition may form beliefs about the quality of labels based on observed prices.

We endow the consumers with relatively simple beliefs, on the rough heuristic that if firms charge different prices, the firm with the higher price is likely to represent higher quality, in the tradition of Milgrom and Roberts (1986), Bagwell and Riordan (1991) and subsequent literature. If so, the configuration of prices affects the interaction among firms through two channels: prices may affect beliefs about quality, but they also allocate demand between the two firms given any set of beliefs about quality. This introduces a potential fragility in the strategic interaction if small differences in prices can, by altering perceptions of quality, lead to large re-allocations of demand. To avoid this we build some 'friction' into the market by positing that consumers interpret a higher price as signaling quality only when prices differ by some non-trivial amount, $\Delta > 0$.[19] Any price differential smaller than Δ is ignored by consumers in forming their beliefs about quality. That agents are boundedly rational in this sense is close in spirit to, for example, the notion of 'just noticeable differences' (see Dziewulski (2016) for a review). Methodologically, without ruling out

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[19]We assume Δ is bounded away from zero, but small enough so that the price differential associated with the full-information case is revealing: specifically that $0 < \Delta < p_h^* - p_l^*$, as given in equations (1) and (2).

the possibility that firms could signal quality through prices it restricts it – an epsilon of price difference is not permitted to fully inform the whole consumer population. This allows us to focus on active information acquisition by consumers - the channel of interest to us – rather than consumers as passive recipients of information, which has already been well-studied both in the wider literature, and also the eco-label literature (for example Harbaugh et al (2011)). A fuller analysis could combine the two more fully, at the cost of substantial additional complexity.

To make this precise we specify consumers' beliefs, common for all consumers, as follows. Let μ_i^0 be the prior probability that the firm i has the more stringent label s_h (and, by inference, that firm j's label, distinct from that of firm i, has lower stringency s_l). With observationally identical firms, it is rational to posit that the prior $\mu_i^0 = 1/2$. Consumers who invest to acquire information learn the meaning of each label directly and perfectly: depending on what they learn, their posterior beliefs are given by either $\mu_i = 1$ or $\mu_i = 0$. For consumers who do not invest in acquiring information posterior beliefs are

$$\mu_i = \begin{cases} 1 & \text{if } p_i > p_j + \Delta, \\ 0 & \text{if } p_i < p_j - \Delta, \\ 1/2 & \text{otherwise.} \end{cases}$$

Together $\{\mu_i^0, \mu_i\}$ capture the evolution of beliefs regarding firm i's label.

We now consider the price-setting game between firms contingent on a fraction $\alpha(\kappa)$ of consumers being directly informed about label meanings. As before, the firm with the more stringent label s_h leads in setting prices. We consider two scenarios: one in which the firm with the low standard chooses to match the leader's price p_h, and the other in which it chooses to diverge from it.

Market shares and profits under price matching

Consider, first, configurations in which the low quality firm chooses to match p_h, the price set by the high-quality firm. Consumers who are directly informed, namely those with $\theta \in [2\kappa, \bar{\theta}]$, would prefer to buy from the known high-quality firm, provided only that $\theta \bar{s}_h - p_h \geq 0$; at a low enough price p_h all directly informed consumers – with mass $[\bar{\theta} - 2\kappa]$ – form a 'captive' market for the high-quality firm.

Consumers who have not invested in information, those with $\theta \in [\underline{\theta}, 2\kappa)$, cannot distinguish between the two labeled firms when prices are identical. They know that one of the products embodies environmental attribute at level s_h and one at s_l but do not know which is which. As such they will regard either labeled option as delivering average level of environmental attribute, $\bar{s} = 0.5(s_h + s_l)$. The demand of consumers of this type is distributed equally between the two labeled firms as long as $\theta \bar{s} - p_h \geq 0$. Consumer with relatively low θ, who would obtain negative

utility if they bought a labeled product at that prevailing price, prefer to go for the brown backstop (which recall delivers zero of the environmental attribute but at price zero).

Demand for the high-quality firm is

$$
q_h(p_h) = \begin{cases} \overline{\theta} - \frac{p_h}{s_h} & \text{if } p_h > 2\kappa s_h, \\ \overline{\theta} - 2\kappa & \text{if } 2\kappa s_h \geq p_h > 2\kappa \overline{s} \\ \left[\overline{\theta} - 2\kappa\right] + \frac{1}{2}\left[2\kappa - \frac{p_h}{\overline{s}}\right] & \text{if } 2\kappa \overline{s} > p_h > \underline{\theta}\overline{s} \end{cases}
$$

At a sufficiently high price p_h only a subset of directly-informed consumers buy the high-label product. For an intermediate range, all informed consumers buy from it but no uninformed customer does (they all prefer the unlabeled backstop). For prices low enough, it sells to all the directly-informed consumers and also gets half of the demand from uninformed consumers who are willing to pay p_h for a 'blind' pick among the labeled alternatives.[20]

On matching price p_h demand for the low quality firm is

$$
q_l(p_h) = \begin{cases} 0 & \text{if } p_h > 2\kappa \overline{s}, \\ \frac{1}{2}\left[2\kappa - \frac{p_h}{\overline{s}}\right] & \text{if } 2\kappa \overline{s} \geq p_h > \underline{\theta}\overline{s} \end{cases}
$$

When p_h is sufficiently large relative to κ, the high-label product 'pre-empts' the market, squeezing out all demand for the low quality firm. At lower prices, it attracts half the pool of uninformed consumers who are willing to buy a labeled product at price p_h.

Consider now the profit-maximizing choice of price by the firm selling the high-label product, p_h. It is easy to show that when information is sufficiently cheap (if $\kappa \leq \frac{\overline{\theta}}{3}$) it is optimal for the high-quality firm to serve only (a subset of) informed consumers; if matching that price, the low quality firm has no demand.

For $\frac{\overline{\theta}}{3} < \kappa < \frac{\overline{\theta}}{2}$, the high quality firm's optimal price $\hat{p}_h^*$, under the expectation that its price will be matched, is

$$
\hat{p}_h^*(\kappa) = \left[\overline{\theta} - \kappa\right]\overline{s}. \tag{8}
$$

Importantly, this profit-maximizing price is decreasing in κ. The intuition is that if information is relatively expensive for consumers to acquire then, other things equal, the set of informed consumers (in whose eyes the two labeled products are differentiated) will be smaller, and the share of consumers in whose eyes the two labeled products are undifferentiated larger. Price competition for the latter group is more intense for the usual reasons, driving down price.

At this optimally-chosen price, market shares for the two labeled firms are

$$
\hat{q}_h^*(\kappa) = \frac{1}{2}\left[\overline{\theta} - \kappa\right], \tag{9}
$$

---

[20]For brevity we ignore the case where $p_h \leq \underline{\theta}\overline{s}$. It is easy to verify that prices this low will not obtain in equilibrium.

and

$$\hat{q}_l^*(\kappa) = \frac{1}{2}\left[3\kappa - \overline{\theta}\right].$$ (10)

Higher κ reduces the market share of the high quality firm as its captive market is eroded, but allows greater space in the market for the low quality firm. The associated profits are then

$$\hat{\pi}_h^*(\kappa) = \frac{1}{2}\left[\overline{\theta} - \kappa\right]^2 \overline{s}.$$ (11)

and

$$\hat{\pi}_l^*(\kappa) = \frac{1}{2}\left[3\kappa - \overline{\theta}\right]\left[\overline{\theta} - \kappa\right]\overline{s}.$$ (12)

Consider the impact of information cost κ on profits for the two labeled firms. The high quality firm's profit is decreasing in κ in this range $[\frac{1}{3}\overline{\theta}, \frac{1}{2}\overline{\theta}]$: more costly information induces a lower price *and* shrinks its market share. On the other hand, as long as the low quality firm chooses to match the leader's price, its profits are strictly increasing this range. At the lowest end of this range, when $\kappa = \frac{\overline{\theta}}{3}$, the low quality firm is entirely preempted and its profit is zero. At the upper end, its profit is $\frac{1}{8}\overline{\theta}^2\overline{s}$.

For values of $\kappa > \frac{1}{2}\overline{\theta}$, information is so costly that no consumer find it worthwhile to acquire information. The market for labeled goods is shared equally between the two firms, with each earning half the joint monopoly profits. The optimal price is $\frac{1}{2}\overline{\theta}\overline{s}$, with each firm selling $\frac{1}{4}\overline{\theta}$ with profits $\frac{1}{8}\overline{\theta}^2\overline{s}$.

It is also useful, for later purposes, to assess the impact of κ on aggregate sales for firms with labeled products. Higher values of κ reduce the sales of the high-quality product but increase sales of the low-quality by a larger amount. Under price matching, aggregate sales of the two labeled firms are

$$\hat{q}_h^*(\kappa) + \hat{q}_l^*(\kappa) = \kappa$$ (13)

for $\kappa \in [\frac{1}{3}\overline{\theta}, \frac{1}{2}\overline{\theta}]$, and are $\frac{\overline{\theta}}{2}$ for higher values of κ. Importantly, in this setting the market *is not covered by the two labeled firms*. An interval of consumers choose the brown or backstop product that bears neither label. Sales of unlabeled products are

$$\hat{q}_0^*(p_h) = \begin{cases} 1 - \kappa & \text{if } \kappa \in \left(\frac{\overline{\theta}}{3}, \frac{\overline{\theta}}{2}\right), \\ 1 - \frac{1}{2}\overline{\theta} & \text{if } \kappa \geq \frac{\overline{\theta}}{2} \end{cases}$$ (14)

To summarize, the market for unlabeled products is (weakly) decreasing in κ.

Departures from price matching

When the firm selling the low-label product 'mimics' the high-label firm by matching its price it attracts half of the uninformed consumers who buy a labeled item, but none of the informed

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consumers. But price matching is not necessarily the best strategy for the low quality firm. In this section we consider situations in which the equilibrium is characterized by the low-label and high-label variants being sold at different prices.

For values of κ equal to or below $\frac{1}{3}\overline{\theta}$, the low quality firm's profit from matching price, $\hat{\pi}_l^*(\kappa)$, is zero. In this range, the low quality firm could do better by charging a price lower than p_h. Given how consumers' beliefs react to significant price differentials (say, for prices $p_l < \hat{p}_h^* - \Delta$), a lower price might reveal its low quality, but would leave it free to charge price low enough to mop up demand from consumers with low willingness to pay for the environmental attribute.

Of course, once the meaning of the firms' labels is revealed through prices to all consumers, the outcome reverts to the full-information case discussed earlier, with firms' optimized profits given as π_h^* and π_l^* in equations (5) and (6).

More generally, it might be profitable for the low quality firm to deviate from price matching whenever $\pi_l^* > \hat{\pi}_l^*(\kappa)$. To identify the range of information cost for which this holds define κ^* such that $\hat{\pi}_l^*(\kappa^*) \equiv \pi_l^*$. Does such κ^* exist? Writing out these expressions, we have

$$\frac{1}{2}\left[3\kappa^* - \overline{\theta}\right]\left[\overline{\theta} - \kappa^*\right]\bar{s} \equiv \left(\frac{2\overline{\theta} - 3\theta}{4}\right)^2 \sigma. \tag{15}$$

At $\kappa = \frac{1}{3}\overline{\theta}$, we have $\hat{\pi}_l^*(k) = 0$, so that the expression on the left is strictly less than that on the right, π_l^*. Further, $\hat{\pi}_l^*(k)$ is continuous and strictly increasing in κ in the interval $(\frac{1}{3}\overline{\theta}, \frac{1}{2}\overline{\theta})$. A sufficient condition, then, for the existence of a critical κ^* in this interval is that $\hat{\pi}_l^*(\kappa) > \pi_l^*$ for $\kappa = \frac{1}{2}\overline{\theta}$. To appreciate the plausibility of the last restriction, note that when firms coordinate their prices through price matching, their profits vary directly with average quality $\bar{s}$. On the other hand, when firms compete in prices, profits vary with σ, the absolute difference in quality levels. We require only that $\bar{s}$ be sufficiently large relative to σ. In what follows, we make the following additional assumption.

Assumption 3 (A3). *We have $\bar{s} > 4\sigma$.*

This Assumption provides a sufficient condition such that for high enough information cost κ both firms will find the price matching regime to be more profitable that the relatively intense price competition under full information. To see this, note that for $\kappa \geq \frac{1}{2}\overline{\theta}$ profits profits under price matching equal $\frac{1}{8}\overline{\theta}^2\bar{s}$ for either firm. It is easy to check that under Assumption 3, this is strictly larger that profits π_h^* and π_l^* as described in equations (5) and (6).

Figure 2 captures these profits for various ranges of information cost under Assumption 3. For the low-quality firm profits are (weakly) increasing in κ. For $\kappa \geq \kappa^*$, they exceed the profits it earns in the full-information case. In contrast, for the high-quality firm profits are (weakly) decreasing in κ and, given Assumption 3, exceed the profits it earns under full-information.
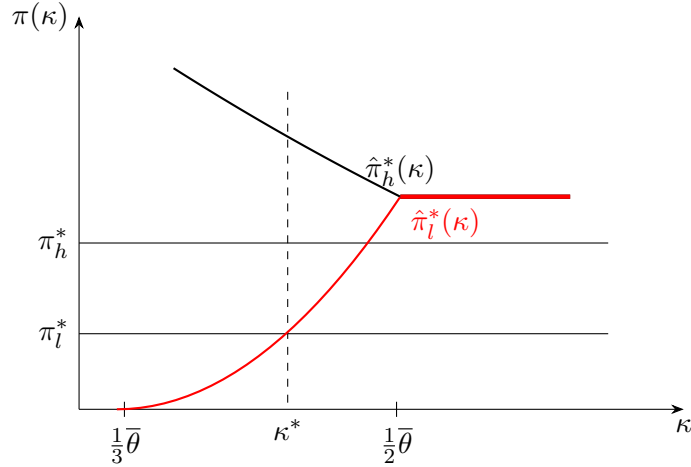
Figure 2: Firms' profits over various ranges of κ.

2.3 Firms' pricing decisions under imperfect information

We now collate our analysis to identify price equilibria for various ranges of information cost κ.

Definition 1 (Price Equilibrium). *Given κ, a price equilibrium is given by the following elements.*

- *Each consumer chooses whether or not to acquire information about the meaning of labels and subsequently decides from which firm to buy given beliefs and preferences.*

- *Firms choose prices sequentially to maximize profits, first p_h for the high quality firm and then p_l for the low quality firm, given consumer beliefs.*

- *Beliefs depend on acquired information and observed prices, as already described.*

We identify two categories of price equilibria.

The first category entails a *pooling equilibrium* in which firms choose a common price p. A fraction of consumers – those with the highest willingness to pay for the green attribute – choose to become informed about the meaning of the labels and buy only from the high quality firm. Consumers with the lowest willingness to pay will not acquire information and will eschew both labeled options in favor of the cheaper brown backstop. However in the middle we have an interval of consumers who care enough about the environment to buy a labeled product, but not enough about the marginal additional greenness implied by the high- over the low-label to invest in the costly information that they would need to allow them to distinguish which was which.

The second category is a *separating equilibrium* in which firms choose different prices, with $p_h > p_l$. Given the information structure, the price difference across firms is large enough to be completely revealing to all consumers. Outcomes in such an equilibrium revert to those described for the full information case in Section 2.1

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The type of equilibrium that obtains depends upon κ; in particular on its value relative to critical threshold κ^*.

Proposition 2. *(Separating equilibrium) For $\kappa < \kappa^*$ a separating equilibrium obtains, with the outcome as described in the full information case.*

The Appendix provides a proof, but the intuition is plain to see. When information acquisition costs are relatively low, a large fraction of consumers chooses to become informed about labels. It is preferable then for the low quality-firm to choose $p_l < \hat{p}_h^*$ rather than match that price. For Δ small enough, the price differential is fully revealing regardless of fraction $\alpha(\kappa)$ of consumers that had chosen to be directly informed. With full information, the optimal prices are p_h^* and p_l^*, with profits π_l^* and π_h^*. The outcome is fully specified in equations (1) to (6).

Proposition 3. *(Pooling equilibrium) A pooling equilibrium exists for $\kappa \geq \kappa^*$.*

When information about labels is relatively costly, only a small fraction of consumers choose to become informed. In that setting, the low quality firm finds it relatively profitable to match the high quality firm's price, sharing the demand from uninformed customers who choose to buy labeled products. Choosing a lower price (to attract customers on price) as the intense price competition associated with that setting leads to lower profits. It could charge a higher price to pretend that it is high quality but when the price premium Δ required to sway beliefs is large enough, this strategy does not increase profits. As Figure 2 shows, for the high quality firm, profits are always higher if the low quality firm chooses to match its prices.

3 Information Provision and Environmental Protection

We now turn to the question of how aggregate environmental outcomes vary with consumers' cost of becoming informed about the true meaning of competing labels.

Calls for more spending on public information and awareness campaigns – which in terms of our model would manifest as reductions in κ – are often heard in this context (see, for example, OECD (1997)). Existing models of green labels have either assumed perfect comprehension of labels by consumers or, in a small number of cases, been populated by sophisticated consumers who are passive learners. As such, and notwithstanding their many merits, they are ill-equipped for the task of understanding how information campaigns influence the active information-gathering efforts of individual consumers.[21]

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[21] We use 'information campaign' here to refer to efforts by government, NGOs, or others to decrease k, the cost of information for consumers. The onus will continue to be on individual consumers to inform themselves about a label, but the information program can reduce the cost of that information acquisition. This is consistent with the careful empirical analysis of Ippolito and Mathios (1990) in the context of health labels on food. They conclude that "analysis of individual food consumption data indicates that theories of information acquisition are important in explaining who responds most quickly to new information; household and individual characteristics that reflect costs of acquiring information, ability to process information, and valuation of health are all important determinants

Our interest lies in the overall environmental damage that obtains under various configurations. Since firms differ in their environmental standards, the overall environmental impact of the industry depends on the distribution of consumer demand across the firms. That is not just the division of demand *within the labeled sector of the market* (since different labels imply different environmental footprints), but also *between the labeled and unlabeled sectors.*

Let z denote the damage per unit of production using the backstop or brown technology (that sold without a label). Labels certify adherence to environmental standards that lower this damage. For the firm with the high-quality label the per unit damage is $z - s_h$, and for the low quality firm it is $z - s_l$ for the low. Plausibly, we assume that $z > s_h$ such that even for the cleanest firm imposes *some* damage.

Aggregate environmental damage depends upon the divisions of output across firms, q_h and q_l for the firms selling labeled products, and q_0 for the unlabeled backstop.

$$Z(q_h, q_l, q_0) = q_h(z - s_h) + q_l(z - s_l) + q_0 z.$$

Below we evaluate aggregate environmental damage in the various settings analyzed earlier, and ask how this varies with the cost of gathering information.

Total environmental damage

At the separating equilibrium, output levels for the firms are given as in the full information case, with q_h^* and q_l^* given by equations (3) and (4). In this case the market is covered by firms with labels, so that q_0^*, the amount sold of the brown unlabeled backstop is zero. Total environmental damage is

$$\begin{aligned} Z^* &= q_h^*(z - s_h) + q_l^*(z - s_l) \\ &= z - [q_h^* s_h + q_l^* s_l] \end{aligned} \tag{16}$$

The term in square brackets measures the total damage reduction associated with sales of the labeled goods against a benchmark in which all good were produced using the unimproved brown technology.

For those values of κ for which a pooling equilibrium obtains – informed customers buy from the firm with the high quality label, and some uninformed customers nonetheless go on to buy one of the labeled variants. Crucially, *the market is not covered completely by two firms with labels* with

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of fiber cereal choices. Moreover, the evidence suggests that advertising reduced. . . the costs of acquiring information for broad segments of the population" (page 459).
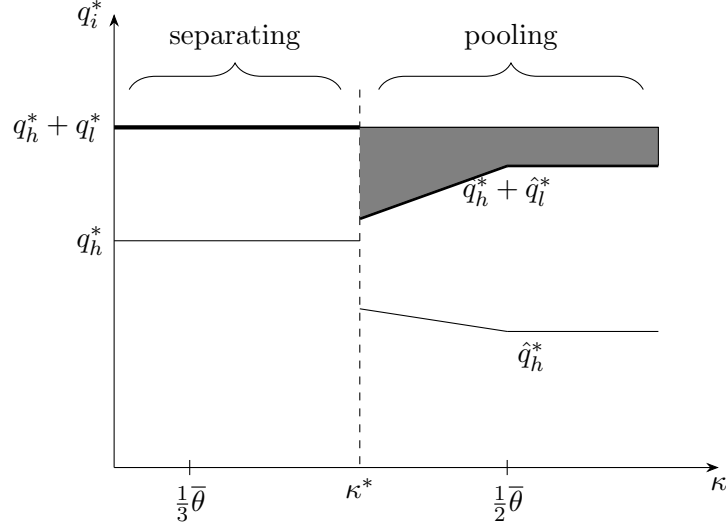
Figure 3: Firms' outputs over various ranges of κ.

some customers falling back on the brown product. Aggregate environmental damage is

$$
\begin{aligned}
\hat{Z}(\kappa) &= \hat{q}_h^*(\kappa)(z - s_h) + \hat{q}_l^*(\kappa)(z - s_l) + [1 - \hat{q}_h^*(\kappa) - \hat{q}_l^*(\kappa)]z \\
&= z - [\hat{q}_h^*(\kappa)s_h + \hat{q}_l^*(\kappa)s_l]
\end{aligned}
\tag{17}
$$

Some results follow. First, total environmental damage is higher at outcomes characterized by pooling equilibria relative to those at separating equilibria. This is due to two effects: (a) the market share of the *high*-label product is greater in the separating equilibrium relative to that at the pooling equilibrium,[22] and (b) the market is completely covered by labeled firms, avoiding any market share for the brown backstop.

The second relates to the impact of variations in κ under pooling. Using values from equations (9) and (10) for $\hat{q}_h^*(\kappa)$ and $\hat{q}_l^*(\kappa)$ in the interval $[\kappa^*, \frac{1}{2}\overline{\theta}]$, we can write

$$
\begin{aligned}
\hat{Z}(\kappa) &= z - \left[\frac{1}{2}(\overline{\theta} - \kappa)s_h + \frac{1}{2}(3\kappa - \overline{\theta})s_l\right] \\
&= z - \frac{1}{2}\overline{\theta}\sigma - (\overline{s} - \sigma)\kappa
\end{aligned}
\tag{18}
$$

Recall that Assumptions 1 and 2 together imply that $\overline{s} > \sigma$. Under those assumptions environmental damage under pooling equilibrium $\hat{Z}(\kappa)$ is *decreasing* in $\kappa > \kappa^*$ in the range $[\kappa^*, \frac{1}{2}\overline{\theta}]$.

At first glance this result is surprising: more costly information can result in greater environmental protection (or, conversely, easier access to information about the meaning of labels results in higher environmental damage). Why does information hurt? Lower κ, by improving access to

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[22]We have $q_h^* = \left(\frac{2\overline{\theta}-\theta}{4}\right)$ and $\hat{q}_h^*(\kappa) = \frac{1}{2}\left(\overline{\theta} - \kappa\right)$. We can check that $q_h^* > \hat{q}_h^*(\kappa)$ for any κ that involves learning.
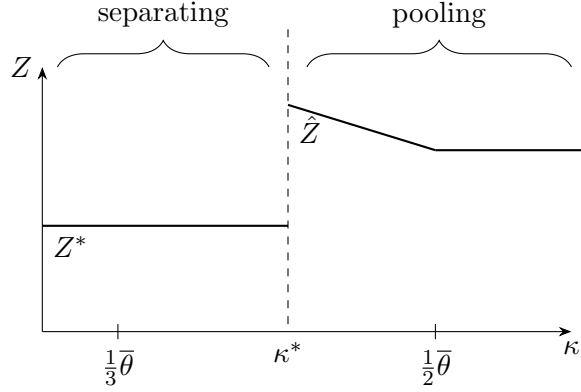
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Figure 4: Aggregate environmental damage as a function of κ.

information, boosts the part of the market 'captive' to the high quality firm (those consumers who have acquired information, such that if they buy a good with a label it will be the one with the high-label). This reduces the intensity of price competition between the sellers of the alternatively-labeled goods, and induces the price of a good carrying *either* label to rise in the pooling equilibrium. These higher prices encourage consumers with a lower willingness to pay for the green attribute to turn their backs on the labeled options altogether and revert to the cheaper, unlabeled brown alternative. While the migration of consumers *within* the labeled sector from the low-label to the high-label supplier implies less environmental damage, this is more than offset by the increase in damage as the part of the market covered by *unlabeled* goods widens.

Figure 3 captures how the market shares of the three firms vary with κ. Pooling equilibria obtain for $k > \kappa^*$. Within the interval $[\kappa^*, \frac{1}{2}\overline{\theta}]$, a reduction in κ induces a rise in the market share of the high quality label, but also increases the share (shaded in the figure) of unlabeled product.

Figure 4 shows how aggregate environmental damage varies with the cost of information. For low values of κ a separating equilibrium obtains, environmental damage is relatively low. For higher values of κ, at pooling equilibria, environmental damage is greater but decreasing in κ for a distinct range of values. We summarize this as the Proposition below.

Proposition 4. *Aggregate environmental damage is non-monotonic in the cost of information κ.*

This suggests that attempts to improve access to information may have mixed results, at least for some ranges of information cost. When the improvement in information is strong enough to tip the equilibrium outcome from one that involves a pooling equilibrium to a separating equilibrium, it improves the environmental outcome. But there is the possibility that smaller improvements may make environmental outcome worse.

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4 Robustness of the model to some modeling choices

In this section we consider the likely sensitivity of our results to certain choices that we made when setting up the model.

4.1 Impact of assuming that the high-quality firm moves first

Our model assumes a sequential choice of prices among labeled firms – the firm with the high-quality label setting its price before the low quality firm. This is introduced largely for expositional clarity. When analyzing the case with imperfect information about labels, we describe the low-quality firm's choice as between matching or not matching the high-quality firm's price. A model of price leadership provides a natural setting in which such choice would arise.

In principle our model's qualitative findings would hold even if prices were chosen simultaneously rather than sequentially, with some additional burden in exposition. The strategic interaction would then consider two cases. The first would be one in which the two firms, choosing prices independently and simultaneously, pick the same price. In other words, we have an outcome with 'matched prices', rather than one following from a decision to match price. In this case the demand allocation rule would remain unchanged from our model. With imperfect information, all informed consumers end up with the high-quality firm and uninformed consumers are split equally across the two as long as the prices were the same. Of course this allows the possibility of multiplicity of equilibria, differing in the value of the matched price, so that we would need to specify ad criteria for equilibrium selection to pick out the best matched-price outcome.

The other case, in which they choose prices that are significantly different would correspond to the case with complete information, but now with simultaneous rather than sequential choice of prices. We have

Proposition 5. *(Modified Proposition 1)* *With perfect information about the quality represented by labels, if firms choose prices simultaneously, equilibrium prices are given by*

$$\tilde{p}_h^* = \left(\frac{2\bar{\theta} - \underline{\theta}}{3} \right) \sigma \tag{19}$$

$$\tilde{p}_l^* = \left(\frac{\bar{\theta} - 2\underline{\theta}}{3} \right) \sigma. \tag{20}$$

It can be observed that this corresponds to the standard textbook outcome (for example, as in Tirole (1988)). At these modified prices, the equilibrium quantities and profits also diverge from

our model, with the latter being

$$\tilde{\pi}_h^* = \left(\frac{2\bar{\theta} - \underline{\theta}}{3}\right)^2 \sigma \tag{21}$$

$$\tilde{\pi}_l^* = \left(\frac{\bar{\theta} - 2\underline{\theta}}{3}\right)^2 \sigma. \tag{22}$$

As in our model, we could compare profits for firms across cases – the one under imperfect information with matched prices versus the one where sufficiently distinct prices reveal information – to obtain a critical value of κ above which a pooling equilibrium obtains. To the extent that profit profit values vary, based on whether prices are chosen sequentially or simultaneously, the computation of this threshold will differ from that in equation (15), but this does not affect our qualitative findings in any meaningful way.

4.2 Assumed complete market coverage under full information

Assumption 2 in our model imposes a lower bound on the preference parameter θ, which ensures that in the equilibrium outcome under perfect information, the market is completely covered by the two labeled firms. Standard analyses of models of vertical differentiation make similar assumptions on the support of the preference parameter (see, for instance, Assumptions 2 on page 296 in Tirole (1988)).

In our setting, our Assumption 2 simplifies the exposition, allowing us to compare incomplete market coverage in the pooling equilibrium with the benchmark of complete market coverage under perfect information. However, our results are not constrained by Assumption 2. If we abandon this assumption on the minimum willingness to pay, labeled firms may prefer to serve only a fraction of the market even under perfect information. Specifically, as we show in the Appendix, without a lower bound on $\underline{\theta}$, with sequential choice of prices, quantities sold at the equilibrium outcome would be

$$q_h' = \frac{1}{2}\bar{\theta},$$

$$q_l' = \frac{1}{2}\bar{\theta}\left[\frac{1}{2 - (s_l/s_h)}\right].$$

Here $q_h' + q_l'$ is less than one, so evidently the market is not fully covered by labeled products even under complete information. However comparing these to quantities at the pooling equilibrium that obtain for $\frac{\bar{\theta}}{3} < \kappa < \frac{\bar{\theta}}{2}$ – see expressions (9) and (10) – we can check that $q_h' > \hat{q}_h^*(\kappa)$ (that consumption of products with high-quality label is lower at the pooling equilibrium) and that $q_h' + q_l' > \hat{q}_h^*(\kappa) + \hat{q}_l^*(\kappa)$ (that aggregate consumption of labeled products is also lower at the pooling equilibrium). In words, even when market is incompletely covered by labeled products under perfect information, the pooling equilibrium that obtains under imperfect information will lead to even lower coverage, with consumers falling back on the 'brown' product to a greater extent. Both

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comparisons mirror the case under Assumption 2 elaborated in our model.

4.3   Impact of assuming that price signaling is "muted"

That price signaling is muted is a non-trivial restriction. In the absence of this assumption the pooling equilibrium would break especially if a firm could signal its label was high quality by raising its price by a miniscule amount: it would then gain market share and increase profit per unit. Further, to the extent that the price differential was revealing to all consumers, it would be unnecessary for consumers to invest in costly acquisition of information.

More generally, in a richer setting than that considered in our model, the price configuration in a differentiated duopoly with imperfect information may serve two functions. It may signal a quality differential – plausibly that the firm with higher price has better quality, while it also serves to allocate demand across the two firms for any given perception of qualities. Both these channels could be smooth variations. First, that the firm with the higher price is more likely (but not certainly) to be of higher quality. Second, the price differential would affect market shares, based on shifting the location of the critical threshold at which consumers are indifferent between the products with distinct labels. The first channel would increase demand and profitability of a firm that raised its price, while the second channel would lower it. Provided there was enough inertia in the first channel, in other words that an increase in price did not raise the perception of quality too much, the second effect might dominate, thereby eliminating the incentive to increase prices. A fully-developed model would require us to select a precise functional form for the impact of price variations on perception of label quality. Adoption of such a functional forms would necessarily be ad hoc and complicate the analysis without adding that much to it. Hence we settled for a relatively stark way of introducing friction into the impact of price variations on quality perception, specifically that variations in price up to some range do not alter quality perception at all, for simplicity.[23]

5   Conclusions

There is a large body of evidence to say that (a) many or most consumers do not recognize eco-labels and (b) even those who do tend not to be very good at understanding what they mean. A robust model of eco-labels requires the process whereby consumers come to comprehend the message contained in labels. This is missing from existing analyses which assume that labels, when applied, are universally understood.

The model we develop takes explicit account of the learning incentives facing consumers – consumers are active players in the model, not passive. They have the opportunity to inform themselves

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[23]Alternatively, we could have made arbitrary assumptions about the impact of price variations on out-of-equilibrium beliefs – as some models do. However these are no less ad hoc than the modeling assumption that we use.

about the meaning of labels that they observe, but only do so if they anticipate that the benefits justify the costs. The accessibility of information is something that government and/or NGOs can influence through educational campaigns. The fraction of consumers that understand a particular label is determined endogenously in the model and it affects how firms price their products. Building the process of active information acquisition into a model with otherwise standard features turns out to impact things significantly in a variety of ways. The model complements the work of Harbaugh et al (2011), Brecard (2014, 2017) and others who have explored the role of eco-labels in settings in which consumer comprehension of their meaning is less than complete.

We use the framework to contemplate the role played by information campaigns in such a model. Public education programs are modeled as reducing the cost that individuals have to bear to acquire information about a label. One would naturally think that the more the public knows about the labels, the better. However, we establish that this is not necessarily the case—environmental benefit from labeling can decrease as consumers become more informed about labels' meaning. If information is sufficient accessible (i.e., not too costly to obtain), the firm bearing the low quality label will wish to compete on price, attracting custom away from the firm with the high quality label. Our model develops the notion of an "efficient amount of misinformation". It is worth recalling explicitly that environmental quality is always better in the separating equilibrium: full information remains better than consumer confusion. However, if some amount of consumer confusion is unavoidable, then sometimes an increase in the cost of information is beneficial.

The mechanism underpinning the seemingly perverse relationship between costliness of information and overall aggregate outcomes is worth reviewing and relies on a careful consideration of how we think about market coverage.

As we have shown, in the pooling equilibrium the market coverage of labeled products is less than full, with some consumers – an interval at the lower end of consumers' willingness to pay (WTP) buying the brown backstop.[24] While those consumers with the highest WTP for the environmental attribute will find it worthwhile to acquire the information that they need to allow them to pick a good carrying the high-label *in particular*, there is an interesting interval of consumers with mid-range WTPs who are motivated enough to buy "a labeled product" over the brown backstop, but not so motivated that they would invest in becoming informed to ensure they can pick "the best" among the labeled alternatives. This latter group remain uninformed, know that there is a half chance that the labeled product they buy embodies s_h and a half chance s_l, and buy that lottery.

Critical to understanding how the cost of information impacts the overall environmental footprint of the sector is how the interval of WTP values covered by that middle set varies with changes in that cost. An increase in the cost of information affects both the lower and upper boundary of that interval, but in ways that have different environmental implication. At the upper end it discourages some acquisition of information, and causes some of those who previously became in-

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[24]The situations in which the pooling outcome prevails are the most interesting. As we have shown, under separation the outcomes reverts to the full-information case, the market is covered by labeled goods and aggregate environmental impact is invariant to the cost of information acquisition.

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formed in order to buy the high-label product in particular, to decide that is no longer worthwhile. At this margin those consumers now fall into the middle group - they revert to buying "a labeled product". This is bad for the environment since some part of demand within the labeled segment of the market is reallocated from the firm selling high-label products to one selling low-. However, as the portion of consumers in the labeled part of the market who are informed goes down, the closer competition between the alternatively-labeled good comes to competition in undifferentiated products.[25] Reduced differentiation intensifies competition between the two labeled goods and drives down prices of both. As this happens an interval of those who previously would have gone for the brown backstop good are induced not to acquire information, but to opt into the middle group who buy "a labeled product". This is good for the environment. Our analysis shows that over part of a range of κ the first effect on the environment outweighs the second, elsewhere that is reversed.

The model would predict real world outcomes in which a premium would be paid for a product carrying one of a set of available labels, compared to a totally uncertified alternative, but with at the same time little or no variation in the size of premium amongst labels.[26]

There are two interesting implications of the model relating to NGO run labels and the recent proliferation of such labels and the ensuing confusion for consumers (see Harbaugh et al. (2011); Fischer and Lyon (2014); Heyes and Martin (2017) for a discussion of label proliferation). First, having multiple labels with only a fraction of consumers informed about labels' meaning can produce a better environmental outcome than having a single universally-understood label, counter to popular discussion. When consumers are only imperfectly informed about the meaning of labels but can exert effort to learn, proliferation of labels can be desirable, and *necessary* for this to be the case is that there be consumer confusion in equilibrium. Second, NGOs operating labeling schemes and interested in improving the environment may wish to deliberately make information about their labels less than perfectly accessible. In this way, the NGOs can induce greater environmental benefits from the firms they certify.

Finally, we acknowledge that the model contains a number of simplifying assumptions. Perhaps the most important among these is the assumption that the technology applied by each firm is fixed. As such while we can speak to how market shares of clean and dirty products may vary with the informational environment, we cast no light on how that might then feed into decisions by firms to adopt cleaner production practices. This is an important extension that remains for future research.

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[25]Recall again, the labels are observationally-distinct. They may be different colors, carry different logos or legends, etc.. However if consumers do not know which physical manifestation corresponds to s_h and which to s_l then in terms of the dimension that matters the goods are undifferentiated. Each offers the buyer a 50/50 lottery over the two attribute values.

[26]The internal conversation that a consumer of the middle type in our model is having with themselves might run as follows: "I see one product carrying a WWF label and one carrying a Greenpeace label. I know either of these will be much better than the cheaper unlabeled competitor. I also suspect that one of the WWF and Greenpeace are more stringent in what they require when they hand out labels. However differences are such that it is not worth me exerting the effort it would take to find out which is which, so I'll just pick whichever."

Appendix

Proof of Proposition 1. Firm h has zero demand at any price $p_h > \bar{\theta} s_h$, so would prefer to choose a lower price. Firm l, with its visibly lower environmental standard, has zero demand when $p_l \geq p_h$ in this range. It is sufficient, then, to focus on cases with $p_l < p_h \leq \bar{\theta} s_h$. For any pair of prices (p_h, p_l), consumers with $\theta \geq \frac{p_h - p_l}{\sigma}$ prefer to buy from firm h and the rest from firm l. Consider the low quality firm's optimal response to the high quality firm's price p_h. Its demand is given by

$$q_l(p_l; p_h) = \begin{cases} \frac{p_h - p_l}{\sigma} - \underline{\theta} & \text{if } p_l \leq \underline{\theta} s_l, \\ \frac{p_h - p_l}{\sigma} - \frac{p_l}{s_l} & \text{otherwise.} \end{cases}$$

Choosing p_l to maximize profits $p_l q_l(p_l; p_h)$, its optimal reaction to p_h is

$$R_l(p_h) = \begin{cases} \frac{1}{2}(p_h - \sigma \underline{\theta}) & \text{if } p_h \leq \underline{\theta}(s_h + s_l), \\ \frac{1}{2} \frac{s_l}{s_h} p_h & \text{otherwise.} \end{cases}$$

Anticipating this response, the high-quality firm's demand is

$$q_h(R_l(p_h), p_h) = \begin{cases} \frac{2\bar{\theta} - \underline{\theta}}{2} - \frac{1}{2\sigma} p_h & \text{if } p_h \leq \underline{\theta}(s_h + s_l), \\ \frac{1}{2} \frac{s_l}{s_h} p_h & \text{otherwise.} \end{cases}$$

Given Assumptions 1 and 2, its profit maximizing price lies in the first of the above ranges, with

$$p_h^* = \left(\frac{2\bar{\theta} - \underline{\theta}}{2}\right) \sigma,$$

so that

$$p_l^* = R_l(p_h^*) = \left(\frac{2\bar{\theta} - 3\underline{\theta}}{4}\right) \sigma.$$

It is straightforward to determine market shares and profits at these equilibrium prices. From Assumption 2, we have $p_l^* < \underline{\theta} s_l$ so that

$$q_l^* = q_l(p_l^*; p_h^*) = \left(\frac{2\bar{\theta} - 3\underline{\theta}}{4}\right)$$

$$q_h^* = q_h(p_l^*; p_h^*) = \left(\frac{2\bar{\theta} - \underline{\theta}}{4}\right)$$

Profits are given by $\pi_l^* = p_l^* q_l^*$ and $\pi_h^* = p_h^* q_h^*$. $\qquad \square$

Proof of Proposition 2. Given κ, a fraction $\alpha(\kappa)$ of consumers are willing to invest in acquiring information. Consider the low quality firm's pricing decision who, as follower in the price-setting sequence, must choose whether or not to match the leader's price. When $\kappa < \kappa^*$, from (15),

we have $\hat{\pi}_l(\kappa) < \pi_l^*$, so the low quality firm would prefer the full-information outcome if it were attainable. Suppose the high quality firm chooses p_h^*, while the low-quality firm chooses p_l^*. For Δ small enough, the price differential is fully revealing regardless of fraction $\alpha(\kappa)$ of consumers that may choose to be directly informed, so that posterior beliefs are $\mu_h = 1$ and $\mu_l = 0$. From Proposition 1, prices p_h^* and p_l^* are best responses to each other in this full information setting, with profits π_l^* and π_h^*. Consumers with $\theta \geq \frac{1}{4}(2\bar{\theta} + \underline{\theta})$ buy the product with hiqh quality label; those with lower θ buy the product with the low quality label.

$\square$

Proof of Proposition 3. Given κ, only consumers with $\theta \geq 2\kappa$ will invest in acquiring information directly. Informed consumers will have posterior beliefs $\mu_h = 1$ and $\mu_l = 0$, while uninformed consumers will have posterior beliefs $\mu_h = \mu_l = 0.5$. From equation (15), for $\kappa \geq k^*$, the proportion of informed consumers is small enough that low quality firm will prefer to match prices (ie., choose $p_l = \hat{p}_h^*$) rather than choose any lower price that would reveal its low quality. Would this firm ever find it profitable to choose a price higher than $\hat{p}_h^*$, in the expectation that choosing a price high enough to would allow it to signal (falsely) that it is high quality? The gain to the low quality firm from doing so is limited by the fact that informed customers will persist with the high quality firm; and even when the size of the captive market is small, it must choosing a price significantly higher to sway beliefs. It is easy to check that under Assumption 3, its profits are decreasing in the premium it charges, so the profitability of this deviation is ruled out by assuming that the Δ, the price premium required to sway beliefs is large enough.

Could the high-quality firm do better by deviating from its chosen price $\hat{p}_h^*$ at the pooling equilibrium? At the pooling equilibrium its profit is at least $\frac{1}{8}\bar{\theta}^2 \bar{s}$. Optimal profits for this firm when firms choose distinct prices are at most $\frac{1}{8}(2\bar{\theta} - \underline{\theta})^2 \sigma$. Given Assumption 3 such deviations from the pooling price are not profitable.

At this equilibrium the pooled price is

$$\hat{p}_h^* = \begin{cases} [\bar{\theta} - \kappa]\bar{s} & \text{if } \kappa \leq \frac{1}{2}\bar{\theta}, \\ \frac{1}{2}\bar{\theta}\bar{s} & \text{otherwise.} \end{cases}$$

At this price, consumers with relaively high willingness to pay for green products (those with $\theta \geq 2\kappa$) choose to be informed and buy the from the firm they know to be high quality. Those with relatively low willingness to pay (those with $\theta < \max[(\bar{\theta} - \kappa), \frac{1}{2}\bar{\theta}]$) buy the unlabeled product. An interval of consumers with intermediate values of θ choose to remain uninformed and pick randomly between the two firms with labeled products.

$\square$

Relaxing Assumption 2

We consider the implications of relaxing Assumption 2 which places a lower bound on $\underline{\theta}$, to ensure that the market is covered by labeled products under complete information. In what follows, we set aside Assumption 2, say, to allow that $\underline{\theta}$ could be as low as zero.

Consider the low-quality firm's demand for any configuration of prices. Generally speaking,

$$q_l(p_l; p_h) = \begin{cases} \frac{p_h - p_l}{\sigma} - \underline{\theta} & \text{if } p_l \leq \underline{\theta} s_l, \\ \frac{p_h - p_l}{\sigma} - \frac{p_l}{s_l} & \text{otherwise.} \end{cases}$$

Choosing p_l to maximize profits its optimal reaction to p_h

$$R_l(p_h) = \begin{cases} \frac{1}{2}(p_h - \sigma\underline{\theta}) & \text{if } p_h \leq \underline{\theta}(s_h + s_l), \\ \frac{1}{2}\frac{s_l}{s_h}p_h & \text{otherwise.} \end{cases}$$

Anticipating this response, the high-quality firm's demand, as price leader, is

$$q_h(R_l(p_h), p_h) = \begin{cases} \frac{2\bar{\theta} - \underline{\theta}}{2} - \frac{1}{2\sigma}p_h & \text{if } p_h \leq \underline{\theta}(s_h + s_l), \\ \bar{\theta} - \frac{1}{2}\frac{p_h}{\sigma}\left[2 - \frac{s_l}{s_h}\right] & \text{otherwise.} \end{cases}$$

Under Assumption 2, the profit maximizing price lies in the first of the ranges in the expressions above. Absent that Assumption, it might lie in the second range. For that case, the profit-maximizing choices of prices are

$$p'_h = \left[\frac{1}{2 - (s_l/s_h)}\right]\bar{\theta}\sigma,$$

$$p'_l = R_l(p'_h) = \left[\frac{(s_l/s_h)}{2 - (s_l/s_h)}\right]\bar{\theta}\sigma.$$

The quantities sold at those prices are

$$q'_h = \frac{1}{2}\bar{\theta},$$

$$q'_l = \frac{1}{2}\bar{\theta}\left[\frac{1}{2 - (s_l/s_h)}\right].$$

Here $q'_h + q'_l$ is less than one, so that the market is not fully covered by labeled products even under complete information.

However compare these to quantities in the pooling equilibrium that obtains for $\frac{\bar{\theta}}{3} < \kappa < \frac{\bar{\theta}}{2}$ where, recall

$$\hat{q}^*_h(\kappa) = \frac{1}{2}\left[\bar{\theta} - \kappa\right]$$

and

$$\hat{q}^*_l(\kappa) = \frac{1}{2}\left[3\kappa - \bar{\theta}\right].$$

Note that $q'_h > \hat{q}^*_h(\kappa)$, so that incomplete information lowers consumption of products with high-quality label.

Also see that as $\kappa \leq \frac{1}{2}$

$$q'_h + q'_l = \frac{\overline{\theta}}{2}\left[1 + \frac{1}{2 - (s_l/s_h)}\right] > \kappa = \hat{q}^*_h(\kappa) + \hat{q}^*_l(\kappa)$$

This inequality says that even when market is incompletely covered by labeled products under perfect information, imperfections in information are likely to lower the coverage even further. Both comparisons (that $q'_h > \hat{q}^*_h(\kappa)$ and $q'_h + q'_l > \hat{q}^*_h(\kappa) + \hat{q}^*_l(\kappa)$) mirror the case under Assumption 2, elaborated in the paper.

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A   Supplementary Appendix (not for publication)

In this supplementary appendix, we elaborate on possible modifications to our model to support our claims that our arguments are robust to many variations.

A.1   Extending the analysis to allow for heterogeneous marginal cost

The model in our paper assumes that marginal cost of production is zero, regardless of quality of label. This extension allows for positive marginal costs c_i that differ across the two firms with labeled products. We assume $c_h > c_l > 0$ for labeled products; and c_0, the marginal cost of the unlabeled product, is set at zero. We restrict attention to the case where $\bar{\theta} s_h > c_h$: otherwise firm h will have zero demand at any price that covers its marginal cost.

Full Information. We begin with the case where all consumers are fully informed about the quality of labels. Once again we focus on price configurations with $p_l < p_h \leq \bar{\theta} s_h$. At any pair of prices (p_h, p_l), consumers with $\theta \geq \frac{p_h - p_l}{\sigma}$ prefer to buy from firm h; those with lower θ prefer to buy from firm l or may fall back on the brown product. Consider the low quality firm's optimal response to the high quality firm's price p_h. Its demand is given by

$$q_l(p_l; p_h) = \begin{cases} \frac{p_h - p_l}{\sigma} - \underline{\theta} & \text{if } p_l \leq \underline{\theta} s_l, \\ \frac{p_h - p_l}{\sigma} - \frac{p_l}{s_l} & \text{otherwise.} \end{cases}$$

Choosing p_l to maximize profits $(p_l - c_l) q_l(p_l; p_h)$, its optimal reaction to p_h is

$$R_l(p_h) = \begin{cases} \frac{1}{2}(p_h - \sigma\underline{\theta} + c_l) & \text{if } p_h \leq \underline{\theta}(s_h + s_l) - c_l, \\ \frac{1}{2}(p_h \frac{s_l}{s_h} + c_l) & \text{otherwise.} \end{cases}$$

Anticipating this response, the high-quality firm's demand is

$$q_h(R_l(p_h), p_h) = \begin{cases} \frac{2\bar{\theta} - \underline{\theta}}{2} - \frac{1}{2\sigma} p_h & \text{if } p_h \leq \underline{\theta}(s_h + s_l) - c_l, \\ \frac{1}{2} \frac{s_l}{s_h} p_h & \text{otherwise.} \end{cases}$$

Its profit maximizing price lies in the first of the above ranges, with

$$p_h^* = \frac{1}{2} \left[(2\bar{\theta} - \underline{\theta})\sigma + (c_h + c_l) \right],$$

so that

$$p_l^* = R_l(p_h^*) = \frac{1}{4} \left[(2\bar{\theta} - 3\underline{\theta})\sigma + (c_h + 3c_l) \right].$$

The market is covered with labeled products as long as $p_l^* \leq \underline{\theta} s_l$. This restriction amounts to

$$\underline{\theta} \geq \frac{2\sigma + (c_h + 3c_l)}{\sigma + 4s_l}.$$

With positive c_h and c_l this assumption is more demanding than Assumption 2 used in the paper. Intuitively, positive marginal costs impose a lower bound on prices of labeled products, which might make it harder to ensure that all consumers buy a labeled product. Those who are deterred would fall back on the dirty product, sold at a price equal to its marginal cost, zero. Our purpose is to explore the environmental consequences of reduction in market coverage as a consequence of informational imperfection. It is useful then to choose parameter configurations that ensure complete coverage in the full information case. To do so, we assume above inequality holds.

It is straightforward to determine market shares and profits at these equilibrium prices under this assumption. The quantities sold by the two labeled firms are

$$q_h^* = \frac{1}{4} \left[(2\bar{\theta} - \underline{\theta}) - \frac{c_h - c_l}{\sigma} \right] \tag{A.1}$$

$$q_l^* = \frac{1}{4} \left[(2\bar{\theta} - 3\underline{\theta}) + \frac{c_h - c_l}{\sigma} \right]. \tag{A.2}$$

Compare these to the case analyzed in our model, which had equal marginal costs for both labeled products (and both values set at zero). Relative to that case, the differentially higher marginal cost for the high quality firm implies that its market share will be smaller and the low quality firm's market share be larger. But once again, the assumption ensures that the market is covered by labeled products: we have $q_h^* + q_l^* = 1$. The associated profits of the firms with labeled products are

$$\pi_h^* = \frac{1}{8} \left[(2\bar{\theta} - \underline{\theta}) - \frac{(c_h - c_l)}{\sigma} \right]^2 \sigma \tag{A.3}$$

$$\pi_l^* = \frac{1}{16} \left[(2\bar{\theta} - 3\underline{\theta}) + \frac{(c_h - c_l)}{\sigma} \right]^2 \sigma. \tag{A.4}$$

Note that in this case, due to its higher marginal cost of production, the high quality firm is not guaranteed to earn higher profits than the low quality firm. However, if the cost differential is not too large, profits would indeed be higher for the high quality firm. One restriction that is sufficient to ensure this: $\underline{\theta} > \frac{c_h - c_l}{s_h - s_l}$. For simplicity we assume this to hold.

Imperfect information We now turn to the case with imperfect information. As before, we assume that consumers with $\theta \geq 2\kappa$ choose to be informed directly.

Consider configurations in which the low-quality firm chooses to match p_h, the price set by the high-quality firm. Consumers who are directly informed, namely those with $\theta \in [2\kappa, \bar{\theta}]$ prefer to buy from the known high-quality firm as long as $\theta \bar{s}_h - p_h \geq 0$; at a low enough price p_h all directly informed consumers form a 'captive' market for the high-quality firm. Consumers who have not

invested in information – those with $\theta \in [\underline{\theta}, 2\kappa)$ – cannot distinguish between the two labeled firms and regard either labeled option as delivering average level of environmental attribute, $\bar{s}$, and their demand is distributed equally between the two labeled firms as long as $\theta\bar{s} - p_h \geq 0$. Consumer with relatively low θ, who not not obtain non-negative utility at that prevailing price, prefer to go for the brown backstop.

Demand for the high-quality firm is

$$q_h(p_h) = \begin{cases} \bar{\theta} - \frac{p_h}{s_h} & \text{if } p_h > 2\kappa s_h, \\ \bar{\theta} - 2\kappa & \text{if } 2\kappa s_h \geq p_h > 2\kappa\bar{s} \\ \left[\bar{\theta} - 2\kappa\right] + \frac{1}{2}\left[2\kappa - \frac{p_h}{\bar{s}}\right] & \text{if } 2\kappa\bar{s} > p_h > \underline{\theta}\bar{s} \end{cases}$$

If the low quality firm chooses to match this price (that is, set $p_l = p_h$) its demand is

$$q_l(p_h) = \begin{cases} 0 & \text{if } p_h > 2\kappa\bar{s}, \\ \frac{1}{2}\left[2\kappa - \frac{p_h}{\bar{s}}\right] & \text{if } 2\kappa\bar{s} \geq p_h > \underline{\theta}\bar{s} \end{cases}$$

If p_h is sufficiently large relative to κ, the high-quality firm pre-empts the market, squeezing out all demand for the low quality firm. At lower prices, uninformed consumers are shared between the two labeled firm as long as they are willing to pay the price. We characterize optimal pricing in a regime of price matching for two cases, depending on the value of κ

Case 1: For $\frac{\bar{\theta}}{3} + \frac{1}{6}\frac{c_h}{\bar{s}} < \kappa < \frac{\bar{\theta}}{2}$, the high quality firm's optimal price $\hat{p}_h^*$, under the expectation that its price will be matched, is

$$\hat{p}_h^*(\kappa) = \left[\bar{\theta} - \kappa + \frac{1}{2}\frac{c_h}{\bar{s}}\right]\bar{s}. \tag{A.5}$$

This profit-maximizing price is decreasing in κ. At this price, market shares for the two labeled firms are

$$\hat{q}_h^*(\kappa) = \frac{1}{2}\left[\bar{\theta} - \kappa - \frac{1}{2}\frac{c_h}{\bar{s}}\right], \tag{A.6}$$

and

$$\hat{q}_l^*(\kappa) = \frac{1}{2}\left[3\kappa - \bar{\theta} - \frac{1}{2}\frac{c_h}{\bar{s}}\right]. \tag{A.7}$$

Higher κ within this range erodes the market share of the high quality firm, but allows greater space in the market for the low quality firm. The associated profits are then

$$\hat{\pi}_h^*(\kappa) = \frac{1}{2}\left[\bar{\theta} - \kappa - \frac{1}{2}\frac{c_h}{\bar{s}}\right]^2 \bar{s}. \tag{A.8}$$

and

$$\hat{\pi}_l^*(\kappa) = \frac{1}{2}\left[3\kappa - \bar{\theta} - \frac{1}{2}\frac{c_h}{\bar{s}}\right]\left[(\bar{\theta} - \kappa)\bar{s} + \frac{1}{2}c_h - c_l\right]. \tag{A.9}$$

Consider the impact of information cost κ on profits. The high quality firm's profit $\hat{\pi}_h^*(\kappa)$ is

decreasing in κ in this range. On the other hand, as long as the low quality firm chooses to match the leader's price, its profits are strictly increasing this range, provided $c_h > 1.5c_l$: we assume this to be true. At the lowest end of this range, when $\kappa = \frac{\overline{\theta}}{3} + \frac{1}{6}\frac{c_h}{\overline{s}}$, the low quality firm is preempted and its profit is zero. At the upper end, its profit is $\frac{1}{8}[\overline{\theta} - \frac{c_h}{\overline{s}}][\overline{\theta} + \frac{c_h}{\overline{s}} - 2\frac{c_l}{\overline{s}}]\overline{s}$.

Case 2: For values of $\kappa > \frac{1}{2}\overline{\theta}$, information is so costly that no consumer find it worthwhile to acquire information. The labeled market is shared equally between the two firms. The optimal price is $\frac{1}{2}(\overline{\theta}\overline{s} + c_h)$, with each firm selling $\frac{1}{4}(\overline{\theta} - \frac{c_h}{\overline{s}})$. Profits for the hiqh-quality firm is $\hat{\pi}_h^* = \frac{1}{8}[\overline{\theta} - \frac{c_h}{\overline{s}}]^2\overline{s}$ and that for the low-quality firm is $\hat{\pi}_l^* = \frac{1}{8}[\overline{\theta} - \frac{c_h}{\overline{s}}][\overline{\theta} + \frac{c_h}{\overline{s}} - 2\frac{c_l}{\overline{s}}]\overline{s}$. Note here that the low quality firm is more profitable as it has an equal market share but lower marginal cost.

Market coverage under price matching. We can quantify the impact of κ on aggregate sales for firms with labeled products. Under price matching, for $\frac{\overline{\theta}}{3} + \frac{1}{6}\frac{c_h}{\overline{s}} < \kappa < \frac{\overline{\theta}}{2}$, aggregate sales of the two labeled firms are

$$\hat{q}_h^*(\kappa) + \hat{q}_l^*(\kappa) = \kappa - \frac{1}{2}\frac{c_h}{\overline{s}}. \tag{A.10}$$

For higher values of κ, they equal $\frac{1}{2}(\overline{\theta} - \frac{c_h}{\overline{s}})$. Either way, the market *is not covered by the two labeled firms.* Sales of unlabeled products are

$$\hat{q}_0^*(p_h) = \begin{cases} 1 - \kappa + \frac{1}{2}\frac{c_h}{\overline{s}} & \text{if } \frac{\overline{\theta}}{3} + \frac{1}{6}\frac{c_h}{\overline{s}} < \kappa < \frac{\overline{\theta}}{2}, \\ 1 - \frac{1}{2}\overline{\theta} + \frac{1}{2}\frac{c_h}{\overline{s}} & \text{if } \kappa \geq \frac{\overline{\theta}}{2} \end{cases} \tag{A.11}$$

For values of κ equal to or below $\frac{1}{3}\overline{\theta} + \frac{1}{6}\frac{c_h}{\overline{s}}$, the low quality firm's profit from matching price, $\hat{\pi}_l^*(\kappa)$, is zero. A significantly lower price might reveal its low quality, but would leave it free to charge price low enough to mop up demand from consumers with low willingness to pay for the environmental attribute. Of course, once the meaning of the firms' labels is revealed through prices to all consumers, the outcome reverts to the full-information case discussed earlier, with firms' optimized profits given as π_h^* and π_l^* in equations (A.3) and (A.4).

More generally, it might be profitable for the low quality firm to deviate from price matching whenever $\pi_l^* > \hat{\pi}_l^*(\kappa)$. To identify the range of information cost for which this holds define κ^* such that

$$\hat{\pi}_l^*(\kappa^*) \equiv \pi_l^*.$$

Does such κ^* exist? At $\kappa = \frac{1}{3}\overline{\theta} + \frac{1}{6}\frac{c_h}{\overline{s}}$, we have $\hat{\pi}_l^*(k) = 0$, so that the expression on the left is strictly less than that on the right, π_l^*. Further, $\hat{\pi}_l^*(k)$ is continuous and strictly increasing in κ up to $\kappa = \frac{1}{2}\overline{\theta}$). A sufficient condition, then, for the existence of a critical κ^* in this interval is that $\hat{\pi}_l^*(\kappa) > \pi_l^*$ for $\kappa = \frac{1}{2}\overline{\theta}$. Writing out the expressions.

$$\frac{1}{8}\left[\overline{\theta} - \frac{c_h}{\overline{s}}\right]\left[\overline{\theta} + \frac{c_h - 2c_l}{\overline{s}}\right]\overline{s} > \frac{1}{16}\left[(2\overline{\theta} - 3\underline{\theta}) + \frac{(c_h - c_l)}{\sigma}\right]^2 \sigma$$

When firms coordinate their prices through price matching, their profits vary directly with average

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quality $\bar{s}$. On the other hand, when firms compete in prices, profits on σ, the absolute difference in quality levels. We require only that $\bar{s}$ be sufficiently large relative to σ, large enough for the above inequality holds.

This essentially replicates the structure of the model, without altering the key mechanism behind our results. For $\kappa < \kappa^*$ we have separating equilibria; $\kappa \geq \kappa^*$ pooling equilibria arise. As is evident, this extension requires some additional notation and further restrictions on parameters (on c_h relative to c_l; and on these values relative to s_h and s_l) but does not alter our qualitative results.