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# Green Lemons

## Environmental Labels and Entry into an Environmentally Differentiated Market under Asymmetric Information

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## Environmental Labels and Entry into an Environmentally Differentiated Market under Asymmetric Information

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*The paper inquires whether a public eco-label mitigates adverse selection, where an ecologically superior (green) product variant is underprovided. A model, integrating entry into a perfectly competitive, vertically differentiated industry and rationally expected quality structure (REQS) under asymmetric information, provides conditions for the label, serving as screening device, to increase green supply and curb pooling. Perverse reactions entail decreasing green supply, enhanced pooling, or increasing non-green supply. It is shown that the common single crossing property disregards the impact of changes in REQS on absolute profitability and may misdiagnose firms' incentives to attain the label. If labelling causes market expansion, pollution may increase even if substitution towards the green variant occurs. However, this only happens if both variants are environmentally sensitive in a well-defined sense.*

JEL classification: L 11, L 15, Q 28

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## 1. Introduction

In recent years many countries have introduced eco-labelling programmes in order to promote the establishment and/or growth of a green market, in which firms sell an environmentally superior (green) variant of some product to purchasers with a willingness to pay for environmental friendliness as a product feature.[1] Moreover, it is hoped for that substitution away from the environmentally inferior (non-green) variant towards the green one takes place so that aggregate pollution is reduced. A label is needed in order to overcome the problem of adverse selection, as first dis-

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[1] See OECD (1997) for an overview of the present state of various centrally managed programmes.

cussed by Akerlof (1970) in his famous 'lemons' article: If consumers are unable to identify a product's true environmental characteristics, non-green producers can sell their variant (the lemon) untruthfully as being green and skim off the green consumers' willingness to pay. Rational purchasers anticipate the incentive to cheat and lower their willingness to pay accordingly. Green producers may then not be able to recover their higher cost of production. This forces them to exit the market or reduces their incentive to enter. The market underprovides the green variant and the market structure (in terms of quality) is distorted towards the non-green variant.

A centrally administered eco-audit with an associated eco-label can be interpreted as a screening mechanism designed to overcome adverse selection by separating firms according to their type, green ($g$) or non-green ($n$). Its type is a firm's private information accessible neither to the labelling-agency nor to purchasers. The agency offers the following set of contracts to firms: (i) 'eco-label in exchange for an audit report which certifies satisfaction of a pre-set range of criteria' or (ii) 'no participation'. If auditing is costly and the set of criteria is specified sufficiently stringently, option (i) is chosen by $g$-producers only and the label separates the types.[2] Then, $g$-producers are able to profit fully from consumers' willingness to pay for environmental friendliness, a $g$-industry establishes and the distortion of market structure is corrected. Notice that the institutional setting of a centrally administered, multi-issue label with voluntary participation corresponds to the ISO type I classification of eco-labels.

From the above follows that eco-labelling evokes two main issues being closely interlinked: The informational asymmetry and market structure, the latter evolving from entry and competitive interaction. On the one hand, due to the problem of adverse selection the role of information is crucial for the evolution of market structure. On the other hand, factual or expected market – or rather quality - structure determines the beliefs of purchasers regarding average environmental friendliness, and, in turn, their willingness to pay for the labelled and unlabelled variant. As this affects firms' expected profits, there is an important feed-back of (expected) market structure on the incentives to obtain a label. Finally, any conclusions as to the effects of labelling on aggregate pollution can only be drawn with reference to market structure. While a brief review of present eco-labelling programmes shows that the interaction of market structure and informational issues is to some extent recognized by labelling-agencies, theoretical models of eco-labelling have, as to my knowledge, so far ignored it. Mattoo and Singh (1994)

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[2] For a theoretical presentation of the concepts of adverse selection and screening consult e.g. Gibbons 1992, Hirshleifer and Riley 1992, or Kreps and Sobel 1994.

analyze market structure effects of eco-labels, but do not address the problem of asymmetric information and the mechanisms to resolve it. Schmutzler (1992) and Crampes and Ibanez (1996) analyze the signalling character of eco-labels. In both cases a monopolist is considered, so that issues of market structure, competition and entry are ignored. Dosi and Moretto (1998) study the effect of an eco-label on investment decisions in polluting product lines, also in the context of a monopolist and without touching informational problems.

The issues of entry and endogenous market structure and rational expectations of average quality under asymmetric information, are integrated in a model of eco-labelling in order to address the following questions. Under which conditions, by which mechanism and to what extent does a centrally administered (type I) eco-label promote $g$-entry, and how are pollution levels affected? In a one period, perfect competition setting of a vertically differentiated industry under asymmetric information, the effects of a central labelling programme on entry of $g$-producers are considered. Labelling is based on a costly eco-audit, the result of which can be expressed by some eco-index. The auditing outcome can be manipulated to some degree. Hence, a $n$-firm may attain a favourable eco-index, however, always at a cost disadvantage. The agency sets a qualification level of the index for awarding the label. After this, firms of either type decide on whether to enter the market and whether to undergo the audit and attain the label. Observing the qualification level and the quantities supplied with and without label, respectively, consumers form rational beliefs over average environmental friendliness, and express their demand.[3] Trading occurs at market clearing prices. The model is solved for the quantities supplied of the $g$- and $n$-variant with and without label, respectively. Comparative statics are used to determine the impact of (small) changes in the qualification level on quantities. It should be stressed that the model's concern with market structure does not relate to any form of strategic behaviour, which is precluded by its perfect competition nature. Market or quality structure, as the share of $g$- and $n$-firms (or output) within the two segments - with and/or without label – of the differentiated industry, matters for two reasons. On the one hand, it is the target variable of labelling policies, on the other hand, it determines consumers' expectations.

A crucial assumption of the model is the presence of rational expectations on behalf of consumers, who forecast average quality correctly. By determining the consumers' willingness to pay this serves to make the firms' pay-offs depend on the evolving quality structure. It turns out that the types' decisions on whether to attain a label hinge on their impact on absolute profitability. The latter is not taken

[3] The model is set up in the context of a commodity market. However, its results carry directly over to intermediate good markets with corporate or public purchasers.

into account by the traditional single crossing property (SCP), which in the model's terms requires for market separation to be feasible that a tightening in the qualification level be strictly more profitable for a $g$- vis-à-vis a $n$-producer (e.g. Gibbons 1992; Kreps and Sobel 1994). As it focuses on relative profitability only, the SCP may misdiagnose the agents' incentives. The model provides scope for the cases of market separation under failure of the SCP and market separation being unfeasible under satisfaction of the SCP. In particular, cases may occur in which a tightening of the qualification level increases the degree of pooling and/or causes the supply of the $g$-variant to fall.

While, in general, the competitive pressure from increased entry of $g$-producers causes $n$-supply to fall, characteristics of demand are identified under which $g$-entry increases the supply of the $n$-variant. For such double expansion of the market or for insufficient substitution away from the $n$-variant introduction of an eco-label may increase pollution levels. However, this is the case only if both variants are environmentally sensitive in the sense that a small increase in a variant's quantity has a positive net impact on pollution with *changes in outside consumption* being taken into account.

A brief review of the literature shows that the interaction of entry decisions, market structure and informational issues is only to some extent recognized by screening models of quality testing and labelling. Much of the literature presumes an exogenous structure of supply with regard to type. The variations of Spence's job market model with a perfect screening technology (Riley 1985) are a case at hand. In a model of imperfect quality testing De and Nabar (1991) take into account endogenous expectations with regard to the tested and untested market segment. However, they do not consider the competitive interaction between segments. Mason and Sterbenz (1994) consider a one period model of asymmetric information and entry in which firms can voluntarily undergo a quality test with a stochastic outcome. Their model, too, does not incorporate the effects of competitive interaction between the different segments. [4] Therefore, it produces a number of similar results, which are, however, mainly driven by the stochasticity of the quality test, while in this model demand side aspects are a driving force. Faulhaber and Yao (1989) consider a model of asymmetric information and endogenous entry in which consumers can become informed about quality by buying third party product reports. Their finding that reducing informational cost increases the number of high quality firms is somewhat related to the argument put forward in this

[4] The same applies to many signalling models, which either exclude competitive interaction by dealing with a monopolist (Milgrom and Roberts 1986, Schmutzler 1992, Crampes and Ibanez 1997) or do not take into account competitive interaction between high and low quality segment (Kihlstrom and Riordan 1984).

paper. However, most of their analysis takes a different angle because of the different informational technology. Biglaiser (1993) analyzes a bargaining model under potential adverse selection. He shows that the presence of a middleman, which may be interpreted as a private auditor, mitigates adverse selection and increases welfare. However, even though a condition for the entry of high quality types is derived, the share of high quality suppliers is not properly endogenized. Moreover, the model differs in that middlemen trade themselves.

The paper is organized as follows. The following section presents the model, section 3 establishes the entry equilibria and develops the comparative static results, section 4 comments on the single crossing property under entry and rational expected quality structure, section 5 derives some implications of labelling for the environment, and section 6 concludes. Some proofs are relegated to an appendix.

## 2. The model

### 2.1 Supply side

In a perfectly competitive setting, a number of $M$ firms produces and sells a differentiated commodity of quality $\theta \in \{g, n\}$, which may be green, $g$, or non-green, $n$. Let the $g$ ($n$)-variant be characterized by a relatively low (high) amount of negative externalities (pollution) caused over its life cycle, or during any one stage of production, transportation, consumption, recycling or disposition, in which the product's impact on the environment is particularly crucial. It should be stressed that while a case from environmental economics is used for illustration, the model extends immediately to any case of vertical differentiation into high and low quality variants. Assume that there are only single product firms in the industry, so that a firm's type corresponds to its product's type, $\theta$, where all firms of a given type are identical. Assume further that each firm's output is bound by a type specific capacity limit $q(\theta)$, and cost is composed of a fixed and variable component, where marginal cost is independent of a single firm's scale. The presence of scale economies together with price taking behaviour under perfect competition then implies that profit maximizing firms face a binary quantity decision. A firm produces at its capacity limit, $q(\theta)$, as long as price exceeds total average cost, evaluated at $q(\theta)$, and, otherwise, does not produce at all. Then,

$$G = \Gamma q(g); \qquad\qquad N = \Lambda q(n) \tag{2.1}$$

give the aggregate quantity of the $g$- and $n$-variant, respectively, which can be decomposed into the number of $g$-firms, $\Gamma$, or $n$-firms, $\Lambda$, and the respective capacity limit, $q(\theta)$. As $q(\theta)$ is a constant, it follows from (2.1) that aggregate quantities, $G$ and $N$, now serve as immediate measures of the number of producers of the respective type, which only change by entry or exit.

A firm's average cost $C(\theta, G, N)$ depends on its type, $\theta$, and the aggregate output levels, $G$ and $N$, and is identical for all firms of a given type.[5] Suppose firms act as price takers on a number of common factor markets, where factor demand and prices increase in aggregate output of the variants. As, at a given point in time, all firms face the same factor prices it is justified to assume average cost to be the same for all firms of a given type. Assume that $g$-production always takes place at a cost disadvantage, such that

$$C(g,G,N) > C(n,G,N) \quad \forall G,N \qquad (2.2).$$[6]

The cost asymmetry may either be caused by an overproportionate fixed cost relating to R&D in emission reducing product or process innovations or to an investment in end-of-pipe technology; or it may be caused by an overproportionate variable cost due to substitution of polluting inputs for more expensive clean inputs. Defining the first partial derivatives of $C(\theta, G, N)$ with respect to $G$ and $N$ by

$$C_G^g := \partial C(g,\cdot)/\partial G\,;\, C_N^g := \partial C(g,\cdot)/\partial N\,;\, C_N^n := \partial C(n,\cdot)/\partial N\,;\, C_G^n := \partial C(n,\cdot)/\partial G\,,$$

the properties of average cost are given by

$$C_G^g > C_G^n > 0; \quad C_N^n > C_N^g > 0 \quad \forall G,N \qquad (2.3).$$

Both types' average cost reacts positively to an increase in either type's aggregate output. Via changes in the price(s) of the common factor(s) variations in industry output are transmitted to changes in average cost as by (2.3). For a variation in $\theta$-type output the impact on $\theta$-type average cost always dominates the impact on non-$\theta$-type average cost, which is explained by type specific proportions in factor use.

*Auditing*

A firm $i$'s type $\theta_i \in \{g,n\}$, $i = 1,2,\ldots,M$, is its private information which can be

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[5] This follows directly from the assumption that firms of a given type are identical. A number of authors use an alternative approach with heterogeneous sellers (e.g. Mason and Sterbenz 1994) or firms (e.g. Faulhaber and Yao 1989), which can be ranked in terms of their valuation or cost.

[6] For sake of simplicity average cost is not split up into fixed and variable cost components. In this model scale effects do not matter for quantities being fixed to capacity and sunk entry costs are of no importance as simultaneous entry is considered.

observed neither by consumers nor by the labelling agency.[7] In order to communicate its type a firm may voluntarily undergo a costly eco-audit. Presume for the sake of modelling simplicity that the outcome of the audit is represented by a single (eco-)quality index $a \in \left[0, a^{max}\right]$. It is assumed that the quality assessment can be manipulated to some degree: It is presumed that fundamental technological uncertainty inhibits any clear grouping of tested products, not even implemented as a stochastic outcome as in Mason and Sterbenz (1994), but only allows for a general assessment of each individual product. This seems reasonable for the type of highly complex quality testing in the environmental context.[8] Under such imperfect auditing technology, a $n$-producer has some scope of concealing his true nature.[9] A second source for manipulation lies in the presence of corrupt auditors who sell for a bribe – in case of agency interns - or at a market price – in case of third party auditors - any quality index asked for, no matter what the true type.[10] Hence, both types may attain any quality index within the feasible range. However, usually this is more costly for a $n$-producer. He has to bear the extra cost of concealing flaws in eco-quality, or, in case of corrupt auditors, has to pay a risk premium included in the audit price or the bribe. The premium accounts for a corrupt auditor's risk of losing his reputation and future earning possibilities should the manipulation of reports be discovered.[11] The auditing cost asymmetry gives rise to a positive, albeit imperfect, correlation between the quality index, $a$, and true type $\theta \in \{g, n\}$: any given index value is achieved at a lower cost by a $g$-producer. Let $A(\theta, a)$ denote average auditing cost as given by total auditing cost divided by the capacity limit, where total auditing cost comprises any expenses the firm incurs in order to ensure attainment of a level $a$. Assume that

$$\begin{aligned} &A(n,a) > A(g,a) > 0, \\ &A_a^n \geq A_a^g \geq 0 \qquad\qquad \forall a \in \left]0, a^{max}\right] \end{aligned} \qquad (2.4),$$

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7 Moreover, if $q(g) \neq q(n)$, a firm's capacity $q_i(\theta)$ is also assumed to be private information as otherwise a firm's type could be inferred from observing capacity.

8 The complex methodology of eco-balances or life-cycle-analysis is a case at hand. Moreover, the German 'Blue Angel' labelling programme, for example, consists of several stages of developing the relevant product criteria, during which the agency relies heavily on outside information even from firms themselves (OECD 1991).

9 Environmentally harmful characteristics of a product may be covered up by temporary improvement of the product's environmental features, for example by manipulation of samples or processes upon the point of inspection, and the diversion of the auditors' attention to dimensions in which the product performs relatively well.

10 Many labelling programmes delegate auditing to third party experts. Moreover, even programmes with inside evaluation, e.g. the 'Blue Angel' programme, usually rely on outside expertise. Widespread anecdotal evidence has it that all firms, $g$ and $n$, produce custom tailored expert reports to confirm their claim of being environmentally friendly on a 'scientifically sound' basis.

11 For a model in which the reputation of middlemen is explicitly considered see Biglaiser (1993).

where $A_a^n := \partial A(n,a)/\partial a$ and $A_a^g := \partial A(g,a)/\partial a$ denote the first partial derivatives. Average auditing cost and its marginal change in the index value are always non-negative for both types, while average auditing cost is strictly greater, and the marginal change is weakly greater for the $n$- as opposed to the $g$-type. Notice that for $q(n) >> q(g)$ a $g$-type may have disadvantage in average auditing cost even when having a strict advantage in total auditing cost. As will be established in Proposition 3.2, $g$-entry occurs only for a $g$-type's strict advantage in average auditing cost. For being trivial, the case of $g$-type's disadvantage in average auditing cost is therefore not pursued any further. Dropping the attribute 'average' for convenience, $A(\theta,a)$ and $A_a^\theta$ are henceforth labelled 'auditing cost' and 'marginal auditing cost', respectively. Marginal auditing cost, $A_a^g$, is positive for the $g$-firm if due to auditing imperfection it has to increase efforts to attain a higher index value. Outside experts are likely to include the additional cost of assessing a higher quality index by use of more sophisticated audit procedures in the price charged for an audit. As a firm wishing to attain a zero index value does not undergo the audit for not having to bear the (potential) fixed cost let $A(n,0) = A(g,0) = 0$.

## 2.2 The consumer's problem and market clearing

Consider a representative consumer who maximizes utility by choosing quantities of the differentiated commodity and an outside composite good subject to his budget constraint and for a given set of prices. While the consumer is completely informed with regard to the composite good he cannot observe the true quality of the differentiated product. However, the consumer forms rational expectations about average quality as follows.

*Beliefs*

The label divides the market into two segments, $j = l,u$, where $j = l$ ($j = u$) relates to the segment with (without) label. Let us introduce as a convention that the term 'separation' refers to type, i.e. green ($g$) or non-green ($n$), whereas 'segmentation' relates to the division of the market by the label. The label is associated with a quality index $a^{min}$, which has been set by the labelling agency as a minimum requirement for awarding the label. Observing $a^{min}$, aggregate supply $Q_j^S$, and the aggregate number of firms $M_j$ in the two segments $j = l,u$, the consumer forms a belief over average quality in each segment, as given by

$$\sigma_j = prob\left(\theta_j = g \middle| a^{min}, Q_l^S, M_l, Q_u^S, M_u\right); \quad j = l,u \tag{2.5}$$

This is the probability that the consumer places on drawing a unit of the $g$-variant from segment $j$ conditional upon the observation of the minimum requirement, supply and number of firms in the two segments. As beliefs are required to be rational, the subjective probability $\sigma_j$ must coincide with the actual share of the $g$-variant in aggregate supply, $Q_j^S$, such that

$$\sigma_j = G_j / Q_j^S \Leftrightarrow 1 - \sigma_j = N_j / Q_j^S; \quad j = l,u, \tag{2.6}$$

Assume that type specific capacities $q(g) \neq q(n)$ are common knowledge.[12] Then, at any state of the system, equilibrium and out of equilibrium, the consumer can calculate average quality with reference to the observation of $M_j$ and $Q_j^S$ only.[13] Notice that in this case the label supplies information about segmentation only; the particular value $a^{min} > 0$ does not transmit any additional information. Moreover, the consumer does not require further information, for example with regard to cost functions, in order to calculate average quality.

*The consumer's problem*

Let the representative consumer's utility be given by

$$U = v(G^D) + w(G^D + N^D, m) \tag{2.7}$$

where $G^D$ and $N^D$ are expected consumption levels of the $g$- and $n$- variant, respectively, and $m$ is consumption of the outside composite. Utility is additive in sub-utility $w(\cdot)$ from 'pure' consumption and an extra private benefit $v(\cdot)$ from consumption of the $g$-variant. The extra benefit may come along with a higher overall quality of the $g$-variant, a warm glow feeling from well-behaving, or social rewards. The effect on aggregate pollution is not taken into account as the consumer does not expect to influence it by his individual choice.[14] Let the first and second partial derivatives of $w(\cdot)$ be given by $w_1, w_m > 0$ and $w_{11}, w_{mm} < 0; w_{1m} = w_{m1} > 0$, respectively. Marginal utility of 'pure' consumption of the differentiated good, $w_1$, is independent of which variant is consumed. Let the first and second derivatives of $v(\cdot)$ be $v' > 0$ and $v'' < 0$, respectively, such that consumption of an additional unit of the $g$-variant increases the extra benefit but

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[12] Note, however, that *individual* firms' capacities $q(\theta_i) \forall i = 1,2,\ldots,M$, are private knowledge.

[13] This can be proved easily by deriving $G_j$ and $N_j$ from the equations $Q_j^S = G_j + N_j$ and $M_j = \Gamma_j + \Lambda_j$ under observation of (2.1).

[14] For a more detailed overview on these issues see Kuhn (1998).

only at a decreasing rate.[15]

The representative consumer maximizes (2.7) by choosing quantities $Q_j^D$ of the differentiated good from the segments $j = l,u$ and a quantity $m$ of the outside good subject to his expectations with regard to average quality

$$G^D = \sigma_l Q_l^D + \sigma_u Q_u^D,$$
$$N^D = (1-\sigma_l)Q_l^D + (1-\sigma_u)Q_u^D, \qquad (2.8a)$$

and the budget constraint

$$I = m + p_l Q_l^D + p_u Q_u^D \qquad (2.8b).$$

Thereby, $p_j$ denotes price in segment $j = l,u$, which the consumer takes as given, and $I$ denotes exogenous income. The composite is used as númeraire, its price being normalized to one. Notice that the consumer maximizes utility over expected values of quantities, which implies risk neutrality.[16] The second order condition is satisfied if $w_{11} w_{mm} \geq w_{1m} w_{m1}$. The first order conditions then give

$$p_j = p + \sigma_j \varpi; \quad j = l,u \qquad (2.9),$$

where

$$p := w_1 / w_m \qquad (2.10) \qquad\qquad \varpi := v' / w_m \qquad (2.11).$$

Expression (2.10) gives the marginal rate of substitution (MRS) between differentiated and outside commodity with regard to pure consumption, and (2.11) the MRS between the $g$-variant and the outside commodity with regard to the extra benefit from $g$-consumption.

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[15] It is easily verified that for individual consumers' preferences being represented by (2.7) the necessary and sufficient conditions for aggregation and representation are satisfied if and only if all second order derivatives are constant within the relevant domain of income and feasible prices. This holds for consumers being heterogeneous with regard to income and/or marginal utility from green consumption $v'$.

[16] The assumption of risk neutral behaviour on the part of consumers may not be quite realistic. The introduction of risk aversion would not change results qualitatively, however, but only complicate analysis.

*Market Clearing prices*

Both market segments are cleared if the two conditions

$$Q_j^D\left(p_l, p_u, \sigma_l, \sigma_u, I\right) = Q_j^S = G_j + N_j; \quad j = l,u \tag{2.12}$$

are satisfied, where $Q_j^D(\cdot)$ are the direct (segment) demand functions following from (2.9), and $G_j$ and $N_j$ are the quantities supplied of the two variants in segment $j$. Market clearing prices are then given by

$$p_j\left(G_j, N_j, G, N\right) = p(G,N) + \sigma_j\left(G_j, N_j\right)\varpi(G,N); \quad j = l,u \qquad (2.13),$$

where $G = G_l + G_u$ and $N = N_l + N_u$.[17] The (implicit) functions $p(G,N)$ and $\varpi(G,N)$, together with a function $m(G,N)$, follow as solutions from the system given by (2.10), (2.11) and the transformed budget constraint

$$I = m + p(G+N) + \varpi G \qquad (2.14).^{18}$$

Thus, the price in each segment $j$ consists of baseline price $p(\cdot)$, capturing the MRS with regard to pure consumption, and a premium $\varpi(\cdot)$, capturing the MRS with regard to the $g$-benefit. The premium is weighted by the expected share of $g$-supply within the segment, $\sigma_j$. Comparative statics of the system (2.10), (2.11) and (2.14) yield the derivatives of $p(G,N)$ and $\varpi(G,N)$ as by

$$p_G := \frac{dp}{dG}; \quad p_N := \frac{dp}{dN}; \quad \varpi_G := \frac{d\varpi}{dG}; \quad \varpi_N := \frac{d\varpi}{dN} \qquad (2.15a).$$

It is easily shown that only

$$p_N < 0 \tag{2.15b}$$

is unambiguously determined. This follows from the interaction of the following effects on baseline price, $p$, and premium, $\varpi$, as caused by changes in supply. An increase in supply of any one variant of the differentiated good has a direct negative effect on $p$ and $\varpi$. First, baseline price and premium must fall in order to adjust to the lower equilibrium MRS between the differentiated and outside good with regard to pure consumption and extra benefit. Second, $p$ and $\varpi$ must fall in

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[17] From now on, by $p_j$ we denote the market clearing price.

[18] Inserting (2.9) together with (2.6) and (2.12) into (2.8b) and rearranging terms yields the transformed budget constraint as given by (2.14).

order to increase the consumer's effective budget for purchase of the additional supply. Additionally, an indirect effect arises from adjustment of the relation between $p$ and $\varpi$ to changes in the implicit MRS, $v'/w_1$, between the $g$-variant as source of the extra benefit and any one variant of the differentiated good as source of utility from pure consumption.[19] Consider an increase in expected supply $N$.[20] Marginal utility from baseline consumption is unambiguously reduced, while the marginal benefit from $g$-consumption remains constant. This tends to lower baseline price and increase the premium. Considering both, direct and indirect, effects, an increase in $N$ unambiguously reduces $p$, as by (2.15b), whereas the impact on $\varpi$ is ambiguous. For an increase in expected supply $G$ the indirect effect is ambiguous as both marginal utility from baseline consumption and the marginal benefit from $g$-consumption decrease. The ambiguity carries over to the aggregate effect. Finally, notice from (2.6) that

$$\sigma_N^j := \frac{d\sigma_j}{dN_j} = \frac{-G_j}{\left(Q_j^S\right)^2} < 0 \qquad \sigma_G^j := \frac{d\sigma_j}{dG_j} = \frac{N_j}{\left(Q_j^S\right)^2} > 0 \qquad (2.16),$$

which capture the impact of changes in supply of either variant on expectations for each particular segment.

## 2.3 Sequence of events and equilibrium concept

Consider the following sequence of events.

Outset: An exogenous innovation has rendered production with the $g$-technology feasible. The new set of technologies $\{g, n\}$ is common knowledge to all potential firms, the agency in charge of labelling, and the representative consumer.

Stage 1: The agency specifies a level of the quality index $a^{min} \in \left[0, a^{max}\right]$ to be produced by any firm wishing to qualify for the label.

Stage 2: The market is opened and potential firms simultaneously choose amongst the following alternatives: enter as a $g$-producer, enter as a $n$-producers, or do not enter. Ex-post switching of technologies, which may give rise to moral hazard, is not possible. The firms' choices are guided by profit maximization, where a firm enters with a capacity $q(\theta_i); \theta_i \in \{g, n\}$; $i = 1,2,\ldots, M$ only if it expects a non-negative profit.

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[19] The implicit MRS follows immediately from division of (2.11) by (2.10).

[20] The consumer rationally anticipates the increase in *aggregate* supply of either variant. Therefore the effects on baseline price and premium are given independently of the changes in the consumer's expectations with regard to the share of $g$-supply within each segment.

Stage 3: Each entering firm chooses a quality index $a_i \in [0, a^{max}]$, $i = 1,2,\ldots, M$ to be delivered to the agency and sinks the auditing cost $A(\theta, a_i)$. It is assumed that for institutional reasons or for reasons of credibility the products' eco-quality can only be communicated to the consumer by the centralized label, so that individual firm labels are excluded from analysis. As the label is granted to any firm transmitting $a_i \geq a^{min}$, profit maximization implies choice of an index value $a_i \in \{0, a^{min}\}$. The label then partitions the market into the two segments $j = l, u$, where $a_u = 0; a_l = a^{min}$.

Stage 4: The representative consumer, being uninformed about $\theta_i$ observes the market data, updates his beliefs according to (2.5) and (2.6), and expresses demand as given by $Q_j^D$ in (2.12). The two market clearing prices are given by (2.13), where all actors are price takers.

An entry equilibrium is given by a market structure $\{G_j*, N_j*\}; \quad j = l, u$, where $G_j*, N_j* \geq 0$, $N_u* + N_l* = N*$ and $G_u* + G_l* = G*$, which satisfies the following set of conditions for $\theta$-type entrants' profit.

$$\begin{aligned}&\pi(\theta, a_j, G_j*, N_j*, G*, N*) = p_j(\cdot) - C(\theta, \cdot) - A(\theta, a_j) \leq 0;\\ &j = l, u; \quad \theta = g, n; \quad a_u = 0; a_l = a^{min}\end{aligned} \qquad (2.17).$$

The four conditions in (2.17) require that for a further producer of either type entry be strictly profitable in neither of the segments. Notice that

$$\pi(\theta, j) < 0: \ \theta = g \Leftrightarrow G_j* = 0 \ \text{and} \ \theta = n \Leftrightarrow N_j* = 0 \qquad (2.18).$$

It is assumed that the number of potential producers of either type is sufficiently large so as not to restrict entry from above.[21] Firms act strictly competitively not only with regard to prices but also with regard to the index value, $a^{min}$, such that there is no strategic behaviour. Hence, the entry equilibrium as by (2.17) constitutes the overall equilibrium depending on the qualification level, $a^{min}$.

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[21] Analysis of the cases in which the equilibrium quantity of either type is bounded from above does not yield any additional insights and is therefore omitted.

## 3. Entry equilibria

Analyis of the entry equilibria proceeds by the following steps. First, a set of necessary and sufficient conditions for $g$-entry is established. Then, from the conditions in (2.17) equilibrium quantities $\left\{G_j^*, N_j^*\right\}; j = l, u$ are determined. Finally, by use of comparative statics the influence of $a^{min}$ on market, i.e. quality, structure is derived.

According to (2.17) entry occurs until

$$p_j = min\left\{C\left(g, G^*, N^*\right) + A\left(g, a_j\right); C\left(n, G^*, N^*\right) + A\left(n, a_j\right)\right\} \quad \forall G^*, N^* \qquad (3.1)$$

From this follows immediately

*Proposition 3.1 If $n$-producers have a cost advantage in unit production cost as by (2.2) $g$-firms never enter the market without a label.*

Proof: See Appendix.

*Corollary 3.1 The price in the $u$-segment is always given by $p_u = p(G,N) + \sigma_u(0,N_u)\varpi(G,N) = p(G,N)$ for $N_u > 0$.*

Proof: Immediate from (2.6) and (2.14) for $G_u^* = 0$.

In the absence of an eco-label the threat of adverse selection inhibits the introduction of the $g$-variant if its production takes place at a cost disadvantage. As a benchmark assume that in the absence of a label, such that $G^* = G_u^* = 0$, $n$-producers can profitably supply a quantity $N^* = N_u^* = N_0 > 0$. As $G_u^* \equiv 0 \Leftrightarrow G_l^* \equiv G^*$ and $\sigma_u \equiv 0$ the indices $j = l, u$ on $'G'$ and $'\sigma'$ are dropped henceforth. Moreover, as $N_u^* \equiv N^* - N_l^*$ the triple $\left\{G^*, N^*, N_l^*\right\}$ can be used as conventional notation for market structure. The benchmark structure is then given by $\left\{0, N_0, 0\right\}$.

Suppose now that a label is introduced. Define

$$\underline{a} := max\left\{a \in \left[0, a^{max}\right] \middle| C\left(g, 0, N_0\right) + A\left(g, a\right) \geq C\left(n, 0, N_0\right) + A\left(n, a\right)\right\} \qquad (3.2)$$

and

$$\overline{a} := max\left\{a \in \left[0, a^{max}\right] \middle| A\left(g, a\right) \leq max\left\{\begin{matrix} p\left(G^*, N^*\right) + \sigma\left(G^*, N_l^*\right)\varpi\left(G^*, N^*\right) \\ -C\left(g, G^*, N^*\right) \end{matrix}\right\}\right\} \text{(3.3).}$$

Then, the following proposition applies.

*Proposition 3.2 Let production and auditing cost be characterized by (2.2) and (2.4), respectively. Then,* $g$ *-firms enter the market with a label if and only if* $a^{nin} \in \left]\underline{a}, \overline{a}\right]$.

Proof: See Appendix.

The label induces $g$-entry if and only if the qualification level, $a^{min}$, meets the following two conditions. As by (3.2), $a^{min}$ must be sufficiently high so as to let the $g$-type's advantage in auditing cost at the least offset the disadvantage in production cost. On the other hand, $a^{min}$ must be bounded from above. Only then, auditing cost does not exceed maximum gross profit attainable by a $g$-firm in equilibrium, as by (3.3), so that the payoff to entry is non-negative. If the label fails to generate $g$-entry, this is anticipated by the consumer who is not willing to pay a surcharge on the labelled products then. Thus, $n$-producers do not have an incentive to attain a costly label and market structure is given by the benchmark $\{0, N_0, 0\}$.

Assuming that the necessary and sufficient conditions for $g$-entry are met, a set of entry equilibrium conditions can be derived from (2.17) for each of the following three cases: (1) $\{G^*, N^*, N_l^*\} \Leftrightarrow N^* > N_l^* \wedge N_u^* > 0$ (pooled supply in $l$-segment and $n$-supply in $u$-segment), (2) $\{G^*, N^*, N^*\} \Leftrightarrow N^* = N_l^* \wedge N_u^* = 0$ (pooled supply in $l$-segment and no supply in $u$-segment), and (3) $\{G^*, N^*, 0\} \Leftrightarrow N^* = N_u^* \geq 0$ (separation: $g$-supply in $l$- and $n$- or no supply in $u$-segment). Consider these regimes in turn.

<u>Regime 1: $\{G^*, N^*, N_l^*\}$ Pooled supply in *l*-segment and *n*-supply in *u*-segment</u>

This equilibrium is characterized by the set of conditions

$$p(G^*, N^*) + \sigma(G^*, N_l^*)\varpi(G^*, N^*) - C(g, G^*, N^*) = A(g, a^{min}) \quad (3.4a),$$

$$p(G^*, N^*) - C(n, G^*, N^*) = 0 \quad (3.4b),$$

$$\sigma(G^*, N_l^*)\varpi(G^*, N^*) = A(n, a^{min}) \quad (3.4c).$$

Equations (3.4a) and (3.4b) are zero-profit conditions for entry by $g$-firms into the $l$-segment and by $n$-firms into the $u$-segment, respectively, while (3.4c) is a no-arbitrage condition requiring that a $n$-firm attains the same (zero) profit in the $l$- and $u$-segment. In the following, the integer problem is ignored and $G$, $N$ and $N_l$ are treated as continuous variables. Define

$$\alpha := p_G + \sigma\varpi_{\mathrm{G}} + \sigma_{\mathrm{G}}\varpi - C_G^g;\ \beta := p_N - C_N^n < 0;$$
$$\gamma := p_N + \sigma\varpi_{\mathrm{N}} - C_N^g;\ \delta := p_G - C_G^n;\ \varepsilon := \sigma\varpi_{\mathrm{G}} + \sigma_{\mathrm{G}}\varpi \quad (3.5),$$

where the derivatives are given as in (2.15a), (2.15b) and (2.16). If the Routh-Hurwitz-conditions

$$|\mathbf{J}| = \sigma_N\varpi[(\alpha\beta - \gamma\delta) - (\varepsilon\beta - \sigma\varpi_L\delta)] = \sigma_N\varpi[(C_N^g - p_N)\delta + (p_G - C_G^g)\beta] < 0 \quad (3.6),$$

$$tr\mathbf{J} = -[\alpha + \beta + \sigma_N\varpi] > 0, \qquad tr\mathbf{J}[\alpha\beta - \gamma\delta + \sigma_N\varpi(p_G - C_G^g + \beta)] + |\mathbf{J}| > 0,$$

are satisfied, then the triple $\{G^*, N^*, N_l^*\}$ gives a unique and stable solution of (3.4a)-(3.4c)., where $\mathbf{J}$ denotes the Jacobian of the system.[22] Application of the implicit function theorem then gives

$$\frac{dG^*}{da^{min}} = \frac{-(A_a^n - A_a^g)\sigma_N\varpi\beta}{|\mathbf{J}|} \geq 0 \quad (3.7),$$

$$\frac{dN_l^*}{da^{min}} = \frac{A_a^n(\alpha\beta - \gamma\delta) - A_a^g(\varepsilon\beta - \sigma\varpi_N\delta)}{|\mathbf{J}|} < 0$$
$$\Leftrightarrow \alpha\beta - \gamma\delta > 0 \vee \frac{A_a^n}{A_a^g} < \frac{\varepsilon\beta - \sigma\varpi_N\delta}{\alpha\beta - \gamma\delta} \quad (3.8),$$

$$\frac{dN^*}{da^{min}} = \frac{(A_a^n - A_a^g)\sigma_N\varpi\delta}{|\mathbf{J}|} \geq 0 \Leftrightarrow \delta \leq 0, \quad (3.9),$$

where $|\mathbf{J}| < 0$ by (3.6), $\sigma_N\varpi < 0$ by (2.16), and the variables in Greek notation as by (3.5).

*Proposition 3.3 Consider the interior equilibrium $\{G^*, N^*, N_l^*\}$. A small increase in the qualification level, $a^{min}$, (i) increases $g$- supply, $G^*$, if and only if the $g$-type has a strict advantage in marginal audit cost, $A_a^n > A_a^g$; and (ii) reduces $n$-supply with a label, $N_l^*$, if and only if the equilibrium reactions of aggregate supplies $G^*$ and $N^*$ causes a net increase in the expectations weighted premium (EWP) falling short of $n$-type's marginal audit cost. (iii) Sufficient for (ii) is that $g$-type's profit decreases under the equilibrium reactions of $G^*$ and $N^*$.*

Proof: See Appendix.

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[22] Constant adjustment velocity equal to one is assumed for all variables.

The intuition behind part (i) of the proposition is the following. After an increase in $a^{min}$ the EWP, $\sigma\varpi$, must increase by the $n$-type's marginal auditing cost in order to restore the no-arbitrage condition (3.4c). Then, for a strict advantage in marginal audit cost, $g$-types' profit increases in $a^{min}$ and gives rise to $g$-entry. According to part (ii) of the proposition a tightening of $a^{min}$ reduces labelled $n$-supply if the equilibrium adjustments of aggregate quantities $G^*$ and $N^*$ either have a negative net impact on the EWP and thus on $n$-firms' additional revenue from entering the $l$-segment, or if the positive net impact on the EWP is too low as to offset $n$-firms' marginal auditing cost. The impact of the adjustments in $G^*$ and $N^*$ on the EWP is composed of the following effects. As by (2.16), there is a positive direct impact as increased $g$-entry raises consumer's expectations over quality. According to (2.15a) the impact on the premium itself is ambiguous for both, changes in $G$ and $N$. In particular, the EWP may sink for an increase in $G$ if $g$-consumption is satiated such that additional supply can only be sold at a substantial reduction in the premium which more than offsets consumers' expectations for a higher average quality. Satisfaction of the sufficient condition given in part (iii) of the proposition guarantees that the EWP cannot increase by more than $n$-type's auditing cost, so that $n$-firms' incentives to enter the $l$-segment are unambiguously reduced. However, if the increase in the EWP more than offsets the $n$-type's marginal audit cost, the positive net-revenue from entering the $l$-segment serves as an incentive for $n$-suppliers to attain the label. Such effect is the likelier the greater the $g$-type's advantage in marginal audit cost, $A_a^n - A_a^g > 0$. This is because the absolute value of the – in this case positive - change in the EWP increases with the extent of $g$-entry which, in turn, positively depends on $A_a^n - A_a^g$. Under the perverse effect, $dG^*/da^{min} < dN_l^*/da^{min}$ cannot be excluded and the degree of pooling, as measured by the ratio $N_l^*/G^*$, may, thus, increase in $a^{min}$.[23]

*Proposition 3.4 Given* $\{G^*, N^*, N_l^*\}$*, a small increase in the qualification level,* $a^{min}$*, decreases aggregate* $n$*-supply,* $N^*$*, if and only if the* $g$*-type has a strict advantage in marginal auditing cost and* $g$*-entry strictly reduces profit in the* $u$*-segment.*

Proof: Immediate from (3.9), where $\delta = p_G - C_G^n = \partial\pi(n,u)/\partial G$.

Intuitively, one would expect a relative increase in the supply of the $g$-variant to tighten (expected) competitive pressure on $n$-firms in the market and thus reduce

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[23] This is easily proved by deriving from (3.7) and (3.8) the condition under which $dG^*/da^{min} < dN_l^*/da^{min}$ and showing that its satisfaction is not precluded by the Routh-Hurwitz conditions.

$n$-entry. However, there is a potential for a perverse effect, by which $n$-supply increases in $a^{min}$. The impact of $g$-entry on $n$- profit in the $u$-segment and, by the no-arbitrage condition, in the $l$-segment is ambiguous. While $g$-entry always raises the cost of $n$-production, the impact on baseline price, $p$, is ambiguous, as by (2.15a). If preferences for the $g$-variant are weak or if the share of $g$-consumers is small, the additional supply of the $g$-variant can trigger a reduction in the premium, $\varpi$, so strong that the purchasing power released allows to raise $p$. If baseline price rises by more than cost, an increase in $a^{min}$ has a positive impact on $N*$. This finding corresponds to the result by Mattoo and Singh (1994), who find that if before labelling $g$-supply exceeds $g$-demand, introduction of the label may raise the price of the $n$-variant by so much that its supply increases. However, besides disregarding the cost side they derive this result from a more rudimentary model not tracing it back to preferences. Other sources for this perverse effect have been identified. Dosi and Moretto (1998) show for a multi-product firm that expected attainment of a label for a $g$-product line may increase investment into a $n$-product line if an image spill-over raises returns to $n$-capital. Moraga-González and Padrón-Fumero (1997) show for a vertically differentiated duopoly that if variants become closer substitutes by virtue of a minimum standard then competition increases and price falls so that $n$-demand may expand.

<u>Regime 2: $\{G*, N*, N*\}$ Pooled supply in *l*-segment and no supply in *u*-segment</u>

In this regime baseline price has been reduced by so much that

$$p(G*, N*) - C(n, G*, N*) < 0$$

and by virtue of (2.18) $N_u* = 0$. Consequently, $N* = N_l*$. In this case of a breaking down of the $u$-segment, the equilibrium is characterized by the conditions

$$p(G*, N*) + \sigma(G*, N*)\varpi(G*, N*) - C(g, G*, N*) = A(g, a^{min}) \quad (3.4a'),$$

$$p(G*, N*) + \sigma(G*, N*)\varpi(G*, N*) - C(n, G*, N*) = A(n, a^{min}) \quad (3.4c'),$$

which are zero-profit conditions for $g$- and $n$-firms, respectively. Define

$$\eta := p_G + \sigma\varpi_G + \sigma_G\varpi - C_G^n > \alpha;\ \kappa := p_N + \sigma\varpi_N + \sigma_N\varpi - C_N^n < \sigma_N\varpi + \gamma \quad (3.10),$$

where the partial derivatives are defined by (2.15a), (2.15b) and (2.16). Then, the quantities $\{G*, N*\}$ form a unique and stable equilibrium of (3.4a') and (3.4c') if the system's Jacobian, $\mathbf{J}'$ satisfies

$$tr\mathbf{J}' = \alpha + \kappa < 0 \quad (3.11a),$$

$$\left|\mathbf{J}'\right| = \alpha\kappa - \eta\left(\sigma_N \varpi + \gamma\right) > 0 \tag{3.11b}$$

where the variables are defined in (3.5) and (3.10). Comparative statics of the system (3.4a')-(3.4c') then give

$$\frac{dG^*}{da^{min}} = \frac{A_a^g \kappa - A_a^n\left(\sigma_N \varpi + \gamma\right)}{\left|\mathbf{J}'\right|} \geq 0 \Leftrightarrow \sigma_N \varpi + \gamma < 0 \wedge \frac{A_a^n}{A_a^g} > \frac{\kappa}{\sigma_N \varpi + \gamma} \qquad (3.12),$$

$$\frac{dN^*}{da^{min}} = \frac{A_a^n \alpha - A_a^g \eta}{\left|\mathbf{J}'\right|} \leq 0 \Leftrightarrow \alpha < 0 \vee \frac{A_a^n}{A_a^g} < \frac{\eta}{\alpha}, \qquad (3.13),$$

where $\left|\mathbf{J}'\right| > 0$ by (3.11b), $\sigma_N \varpi < 0$ by (2.16) and the variables in Greek notation as by (3.5) and (3.10).

*Proposition 3.5 Consider the interior equilibrium* $\left\{G^*, N^*, N^*\right\}$. *A small increase in the qualification level,* $a^{min}$, *(i) increases* $g$*-supply,* $G^*$, *if and only if the equilibrium reaction of* $N^*$ *bears a net impact on* $g$*-profit, which exceeds (falls short of)* $g$*-type's marginal audit cost for the case that* $g$*-profit decreases (increases) in* $G$*; and (ii) reduces* $n$*-supply,* $N^*$, *if and only if the equilibrium reaction of* $G^*$ *bears a net impact on* $n$*-profit, which falls short of (exceeds)* $n$*-type's marginal audit cost for the case that* $n$*-profit decreases (increases) in* $N$. *(iii) It is necessary for part (i) that* $g$*-profit decreases in* $N$ *and sufficient for part (ii) that* $g$*-profit decreases in* $G$.

Proof: See Appendix.

According to part (iii) of the proposition a tightening of $a^{min}$ has a negative impact on $g$-supply if $g$-profit increases in $n$-supply. Albeit being not very likely, this may occur if additional $n$-supply lowers baseline price by so much that the purchasing power released allows for an overproportionate increase in the premium. If a more stringent label forces $n$-producers from the market, the number of $g$-firms falls likewise. Still a label is necessary to put a restriction on $n$-entry as otherwise the consumers' expectation of a $g$-purchase, $\sigma$, would drop to zero and so would the EWP. With regard to the qualification level $a^{min}$ there exists a trade-off between the potential to separate the types by generating a cost advantage for the $g$-type on the one hand, and the absolute auditing cost imposed on the $g$-type on the other hand. A tighter $a^{min}$ reduces $g$-supply if the increase in net profit due to curtailed pooling falls short of the increase in auditing cost. The trade-off does not exist under regime 1, where a $n$-producer has an option to produce in the $l$- or $u$-segment. Baseline price and production cost being equal in both segments, a $n$-firm's selection of the segment is based only on the EWP vis-à-vis the audit cost. Consequently, for an increase in $a^{min}$, the EWP must incline by an amount at the least equal to $n$-type's marginal audit cost. No effects on baseline price or production cost arise from $n$-types' decision to attain a label, which does not effect aggregate $n$-supply. Hence, for the advantage in marginal audit cost, $g$-profit never declines. As the $n$-producer may only enter the market with a label under regime 2, switches in $a^{min}$ affect aggregate $n$-supply and thus baseline price and production cost. The offsetting effects become more complex, as characterized in part (i) of the proposition and give rise to the trade-off. By part (ii) and (iii) of the proposition a tightening of $a^{min}$ entails a perverse increase in $n$-entry into the $l$-segment under the same conditions as discussed for part (ii) of proposition 3.3. Again, it is possible that the degree of pooling increases in $a^{min}$,[24] whereas a simultaneous decrease in $g$-supply and increase in $n$-supply is precluded by stability.[25]

Regime 3: $\{G^*, N^*, 0\}$ Separation; *g*-supply in *l*-segment and *n*- or no supply in *u*-segment

In this regime the $n$-type's auditing cost is so high that

$$\sigma(G^*,0)\varpi(G^*,N^*) + min\{0, p(G^*,N^*) - C(n,G^*,N^*)\} < A(n,a^{min})$$

such that no $n$-firm has an incentive to attain a label and $N_l^* = 0$. the label fully separates the types. As $\sigma(G^*,0) = 1$ the price in the $l$-segment reflects the consumer's full (marginal) willingness to pay for the $g$-variant. The equilibrium is characterized by the conditions

$$p(G^*,N^*) + \varpi(G^*,N^*) - C(g,G^*,N^*) = A(g,a^{min}) \qquad (3.4a''),$$

$$p(G^*,N^*) - C(n,G^*,N^*) \leq 0 \qquad (3.4b'')$$

The equilibrium quantities $\{G^*, N^*\}$ follow as a unique solution from (3.4a'') and (3.4b''), where $N^* = 0$ if (3.4b'') holds as strict inequality. For $N^* > 0$ the system is stable if and only if for the Jacobian $\mathbf{J}''$

$$|\mathbf{J}''| = \alpha\beta - \gamma\delta > 0 \qquad tr\mathbf{J}'' = \alpha + \beta < 0$$

where the variables are defined as in (3.5). Then,

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[24] This is easily proved by deriving from (3.12) and (3.13) the conditions under which $dG^*/da^{min} < dN^*/da^{min}$ and showing that their satisfaction is not precluded by stability.

[25] It can be shown that $dG^*/da^{min} < 0 < dN^*/da^{min}$ contradicts (3.11a) and (3.11b).

$$\frac{dG^*}{da^{min}} = \begin{cases} \frac{A_a^g \beta}{|\mathbf{J}''|} < 0 & \text{if } N^* > 0 \\ \frac{A_a^g}{\alpha} < 0 & \text{if } N^* = 0 \end{cases} \quad (3.14),$$

$$\frac{dN^*}{da^{min}} = \begin{cases} \frac{-A_a^g \delta}{|\mathbf{J}''|} & \text{if } N^* > 0 \\ 0 & \text{if } N^* = 0 \end{cases}, \quad (3.15),$$

where $|\mathbf{J}''| > 0$ and the variables in Greek letters as given in (3.5).

*Proposition 3.6 Given the equilibrium $\{G^*, N^*, 0\}$, i.e. full separation, a small increase in the qualification level, $a^{min}$, (i) decreases $g$-supply; and (ii), given that $N^* > 0$, increases aggregate $n$-supply if and only if profit in the $u$-segment decreases in $g$-supply.*

Proof: Immediate form (3.15) and (3.16), where $\delta = p_G - C_G^n$.

Once separation is achieved a further increase in the qualification level solely increases the $g$-producers' cost of attaining the label and thus reduces entry. The reaction of $n$-producers is ambiguous for the reasons discussed above.

A caveat to the above findings is that they are derived from comparative static analysis. Therefore, the Routh-Hurwicz-Theorem applies to local stability and thus within a neighbourhood of $\{G^*, N^*, N_l^*\}$ only. With no market being existent at the outset, existence of a stable trajectory from a 'non-market' structure $\{0,0,0\}$ to $\{G^*, N^*, N_l^*\}$ has thus to be assumed.

From a modelling as well as from a policy point of view it would be convenient if the implicit functions $G^*(a^{min})$, $N^*(\cdot)$ and $N_l^*(\cdot)$ could be fully developed along the interval $]\underline{a}, \overline{a}]$. However, for three reasons this is not possible without placing a number of restrictions on the model. First, equilibrium reactions of quantities, as given by (3.7)-(3.9), and (3.12)-(3.15), respectively, are functions of the equilibrium quantities themselves. Hence, changes in equilibrium quantities feed back on their respective reactivity altering their impact and possibly sign. Second, even though it can be shown that the separation regime 3, if existent, always lies in an interval $[a^{sep}, \overline{a}]$, it is not clear whether regime 1 or 2 obtains at the lower bound $\underline{a}$. This is because the implicit functions are not continuous at $\underline{a}$. Finally, the implicit functions are differentiable within each single regime but not necessarily at the boundaries. Hence, the existence of any single one regime is not guaranteed and the ordering of the pooling regimes, if both exist, is ambiguous. In principle, a set of existence conditions for the various regimes could be established. Employing additionally a number of conditions to restrict the signs of the reactivities in subsequent regimes, one could derive a number of sequences of regimes contingent on the characteristics of the inverse demand and cost functions. The aim of the paper, being a more general identification of the mechanisms behind labelling, however, does not warrant derivation of more specific results upon a multitude of additional structure.

## 4. Relation to the Single Crossing Property

From a theoretical point of view it is interesting to relate the above results to the Single-crossing-property (SCP) or Spence-Mirrlees-condition which is a necessary condition for attainment of a separating equilibrium in most screening and signalling models. Essentially, it requires the net gain from an increase in the signal level to be greater for the $h$- vis-à-vis the $l$-type (e.g. Gibbons 1992; Kreps and Sobel 1994). For regime 1 this can be expressed as

$$\begin{aligned}\frac{d\pi(g,l)}{da^{min}} &= \alpha\frac{dG}{da^{min}}+\gamma\frac{dN}{da^{min}}+\sigma_N\varpi\frac{dN_l}{da^{min}}-A_a^g\\ &\geq \varepsilon\frac{dG}{da^{min}}+\sigma\varpi_N\frac{dN}{da^{min}}+\sigma_N\varpi\frac{dN_l}{da^{min}}-A_a^n=\frac{d[\pi(n,l)-\pi(n,u)]}{da^{min}}\end{aligned}.$$

Substituting $dN/da^{min}=(dN/dG)(dG/da^{min})=-(\delta/\beta)(dG/da^{min})$, as following from total differentiation of (3.4b), yields

$$\frac{\alpha\beta-\gamma\delta}{\beta}\frac{dG}{da^{min}}+\sigma_N\varpi\frac{dN_l}{da^{min}}-A_a^g\geq\frac{\varepsilon\beta-\sigma\varpi_N\delta}{\beta}\frac{dG}{da^{min}}+\sigma_N\varpi\frac{dN_l}{da^{min}}-A_a^n \quad (4.1).$$

The variables are given by (2.16), (3.5) and (3.10). Consider a small change in $a^{min}$. Adjustment in expected supply then occurs until $d\pi(\theta,l)/da^{min}=0$ for both types $\theta=g,n$.[26] This follows immediately from the notion of zero-profit equilibrium and is checked by inserting the equilibrium reactivities (3.7) and (3.8) into (4.1). Each side of (4.1) individually adds up to zero then. Obviously, the SCP does not only depend on marginal auditing cost but crucially hinges on the effects of changes in supply on price and average production cost. It is easily shown that (4.1) holds as a strict inequality for $dG/da^{min}<dG^*/da^{min}$ so that the SCP is

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[26] As the comparative static argument refers to an ex-ante entry situation, reference is properly made to changes in expected supply for different values $a^{min}$. For instance, $dN_l/da^{min}<0$ does not imply that $n$-supply is reduced by exit from the $l$-segment but rather that expected entry into the $l$-segment is reduced relative to a lower level of $a^{min}$.

strictly satisfied along the adjustment path.[27] However, under stability the changes in supply work towards an equilibration of (4.1), This is easily seen for $(d/dt)(dG/da^{min})>0$ under observation of (3.6). The (relative) increase in $g$-supply always weakens the $g$-type's advantage in net profitability and, thereby, the SCP until in equilibrium, for $dG/da^{min} = dG^*/da^{min}$, (4.1) holds as an equality and the SCP (weakly) fails.

The influence of quantity effects on the $n$-type's incentives to pool by attaining a label are best illustrated by the following counterintuitive examples. First, consider $A_a^n = A_a^g$. According to (4.1) the SCP (weakly) fails. By (3.7) and (3.8), $dG^*/da^{min} = 0$ and $dN_l^*/da^{min} < 0$. According to (4.1), $dG/da^{min} > 0$ contradicts the SCP and can be no stable reaction. Suppose now $dG/da^{min} \leq 0$ and consider the change of profitability for the $n$-type as given by the RHS in (4.1). The increase of $a^{min}$ bears a negative impact on profit which can only be offset by an increase in the EWP, $\sigma\varpi$. For $dG/da^{min} \leq 0$ this only is achieved by a reduction in supply $N_l$. Hence, no matter what the reaction of $g$-producers, $dN_l/da^{min} < 0$. This fully restores the $g$-firms' profitability so that $dG/da^{min} = 0$. Even though the SCP (weakly) fails the degree of pooling is reduced. The underlying rationale is that attainment of the label by a $n$-type not only requires the SCP to fail, such that entering the $l$-segment is relatively profitable vis-à-vis the $g$-type, but also requires pooling to be profitable in absolute terms. However, under rational expectations the EWP and thus the return to pooling are reduced with the degree of pooling. This puts an upper ceiling on the incentive to pool and, thereby, mitigates the problem of adverse selection even under failure of the SCP.

Now consider $A_a^n > A_a^g = 0$ and $\alpha\beta - \gamma\delta < 0$. As easily verified from (4.1) the SCP is satisfied for $dG/da^{min} < dG^*/da^{min}$. Nonetheless, according to (3.8), $dN_l^*/da^{min} > 0$. Observation of the LHS of (4.1) shows that $dG/da^{min} > 0$ increases $g$-profit, an inherently unstable tendency. However, if ongoing $g$-entry increases the EWP by so much that $n$-type's marginal auditing cost is more than offset and the (absolute) return to attaining a label becomes positive the number of $n$-firms, which enter the $l$-segment, increases. The two examples render obvious a shortcoming of the 'traditional' SCP in models with rational expectations and endogenous market structure. By its very nature the SCP only addresses relative prof-

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[27] The adjustment path, too, relates only to expected supply. While, in reality expected quantities are likely to switch instantaneously the reaction path is used as a fiction to make the interpretation of the SCP more accessible. One may think of some tâtonnement during which potential producers are asked in turn whether they are willing to enter the market for a given $a^{min}$. This would give rise to a finite time of reaction where expected supply results from aggregation of the announcements.

itability between the two types. This is sufficient for all models in which profitability only depends on the value of the signal, while for a given signal profitability is either independent of market (and quality) structure, or market structure itself is fixed. However, under rational expectations absolute profitability depends on market structure. Then, the SCP's failure to incorporate the effects of absolute profitability on the $n$-type's incentives to pool leads to misdiagnose. Whereas the first example has shown that the SCP is not a necessary condition for market separation, the second has shown that it is not a sufficient condition either. Analysis for regime $2$ is omitted but can be shown to produce a similar result. Thus

*Proposition 4.1 In models of rational expectations and endogenous market structure absolute profitability of entering the high quality (here: $l$-) segment becomes endogenous with regard to market structure. For $a^{nin} \in \left]\underline{a}, \overline{a}\right]$, the SCP is neither necessary nor sufficient for market separation. It, therefore, needs to be amended for the effects of changing market structure on absolute profitability.*

A caveat to the above findings is that our findings only apply to a comparison of different market structures involving $g$-entry. However, unless the $g$-type´s advantage in average auditing cost is so great that $\underline{a} \to 0^+$ a label generates $g$-entry only if $A_a^n - A_a^g > 0$ over a sufficient part of the interval $\left]0, \underline{a}\right]$. As for all $a^{min} \in \left[0, \underline{a}\right]$ market structure is $\{0, N_0, 0\}$, the SCP is given by $A_a^n - A_a^g > 0$ over $\left]0, \underline{a}\right]$ and must hold consequently.

## 5. Environmental impact

The ultimate objective of an eco-labelling scheme lies not that much in the creation of a green market but rather in the reduction of pollution. Thus at least brief reference should be paid to this point. Consider

$$E(G, N, m); E_N > E_G \geq 0; E_m \geq 0 \qquad (5.1),$$

giving the aggregate emission level as a non-decreasing function in the quantities $G$, $N$ and $m$.The first partial derivatives with respect to the quantities $E_Q = \partial E / \partial Q; Q = G, N, m$ can be interpreted as unit emissions. Then, $E_N > E_G \geq 0$ reflects the assumption that the $g$-variant is associated with a lower degree of lifetime externalities than the $n$-variant. Totally differentiating (5.1) with respect to $a^{min}$ yields

$$\frac{dE}{da^{min}} = E_G \frac{dG^*}{da^{min}} + E_N \frac{dN^*}{da^{min}} + E_m \frac{dm}{da^{min}} \qquad (5.2).$$

Total differentiation of the budget constraint in equilibrium

$$m = I - (p^* + \sigma^* \varpi^*)[G^* + N_l^*] - p^* N^*$$
$$= I - [C(g,\cdot) + A(g,\cdot)]G^* - [C(n,\cdot) + A(n,\cdot)]N_l^* - C(n,\cdot)[N^* - N_l^*]$$

with respect to $a^{min}$ yields

$$\frac{dm}{da^{min}} = \frac{\partial m}{\partial G}\frac{dG^*}{da^{min}} + \frac{\partial m}{\partial N}\frac{dN^*}{da^{min}} - \zeta \qquad (5.3),$$

where

$$\frac{\partial m}{\partial G} = -\left(p^* + \sigma^* \varpi^* + C_G^g G^* + C_G^n N^*\right) < 0;$$
$$\frac{\partial m}{\partial N} = -\left(p^* + C_N^g G^* + C_N^n N^*\right) < 0 \qquad (5.4),$$

give the impact of marginal changes in $G$ and $N$ on $m$ and

$$\zeta := A(n,\cdot)\left(dN_l^* / da^{min}\right) + A_a^g G^* + A_a^n N_l^*$$

gives the impact on $m$ of the change in aggregate auditing cost. According to (5.2) and (5.3) the impact on aggregate emissions of a marginal change in the qualification level is not only determined by the change in quantities of the $g$- and $n$-variant, respectively, but also by the change in consumption of the composite, $m$.[28] Inspection of (5.4) shows that for a constrained budget, changes in consumption of the $g$- and $n$-variant are reflected in opposing changes in outside consumption $m$. Notice that the impact of quantity changes on production and auditing cost as transmitted by price changes is accounted for. Inserting (5.3) into (5.2) and rearranging terms yields

$$\frac{dE}{da^{min}} = \left(E_N + E_m \frac{\partial m}{\partial N}\right)\left(\frac{dG^*}{da^{min}} + \frac{dN^*}{da^{min}}\right)$$
$$+ \left[E_G - E_N + E_m\left(\frac{\partial m}{\partial G} - \frac{\partial m}{\partial N}\right)\right]\frac{dG^*}{da^{min}} - E_m \zeta \qquad (5.5).$$

The impact of a change in the qualification level can, thus, be hypothetically separated into three distinct effects. The term on the RHS of the first line of (5.5) gives

[28] I am grateful to Michael Kosz for bringing this point to my attention. Surprisingly, this general equilibrium effect is overlooked by many eco-labelling practicioners as well as by much of the literature. Of course, the effect does not arise in a partial equilibrium setting.

a market size effect. It captures the impact on aggregate emissions of changes in aggregate quantity of the differentiated good evaluated at the net emission impact of the $n$-variant. The induced change in outside consumption is included as an offsetting effect to marginal emissions from the $n$-variant. The first term in the second line gives a substitution effect, where the change in $g$-consumption is evaluated at the differential net emission impact of the $g$-vis-à-vis the $n$-variant. The second term gives the impact from changes in aggregate auditing cost as transmitted by a change in $m$. In the following we neglect this latter effect under the presumption that it is comparatively small.

Definition 5.1: Call a variant environmentally sensitive (insensitive) if

$$E_Q + E_m \, \partial m/\partial Q > (<) 0; \quad Q = G,N$$

such that a small increase in quantity yields a positive (negative) net impact on aggregate emissions with *changes in outside consumption* being taken into account. [29]

Now, suppose the impact of $g$-entry on both types' production cost is sufficiently strong vis-à-vis the impact of $n$-entry so that under observation of (5.4)

$$\partial m/\partial G < \partial m/\partial N \Rightarrow E_G + E_m \frac{\partial m}{\partial G} < E_N + E_m \frac{\partial m}{\partial N} \qquad (5.6).$$

Then, the net increase in emissions is always smaller for a marginal increase in $g$-supply than for an increase in $n$-supply. Thereby, the substitution effect in (5.5) is unambiguously negative, implying that substitution of $g$- for $n$-consumption reduces emissions. However, the market size effect remains ambiguous for two reasons. First, the market may expand or shrink for a given net emission impact from $n$-consumption. Second, the net emission impact may be positive or negative as depending on the $n$-variant's environmental sensitivity.

*Proposition 5.1 Suppose (5.6) holds and consider a marginal increase in $a^{min}$. Then aggregate emissions are reduced (i), in case of both variants being environmentally sensitive, if and only if aggregate $n$-supply is reduced and the change in $g$-supply is such that the differentiated sector either shrinks or does not expand by too much; (ii), in case of the $n$-variant being environmentally sensitive but not the $g$-variant, if substitution takes place such that $n$-supply decreases and $g$-supply increases; and (iii), in case of both variants being environmentally insensitive, if*

[29] If for high production cost and selling price a small increase in a variant's consumption induces a large reduction in outside consumption this may lower aggregate emissions even if marginal e-missions from the variant exceeds that from the outside good.

*and only if aggregate $g$-supply is increased and the change in $n$-supply is such that the differentiated sector either grows or does not shrink by too much.*

Proof: See Appendix.

Case (i) of the proposition refers to a situation, in which the differentiated good is environmentally sensitive vis-à-vis outside consumption because of relatively high marginal emissions even of the $g$-variant or because of little influence on outside consumption levels. Then, in case of an expanding market, aggregate emissions decline if and only if additional emissions generated are more than offset by a decrease in the average emission level owing to a sufficient degree of substitution towards the $g$-variant. Clearly, this implies that $n$-supply must fall. If the stricter qualification level leads to a shrinking of the market, aggregate emissions decrease unambiguously. Case (ii) refers to a situation in which only the $n$-variant is environmentally sensitive, whereas $g$-consumption is environmentally insensitive. For aggregate emissions to decrease in reaction to a tightened qualification level, it is then sufficient that substitution of $g$- for $n$-consumption take place, while changes in market size are irrelevant. Finally, for case (iii), where both variants of the differentiated good are environmentally insensitive, the results from (i) are reversed. Now, an expansion of the differentiated market effects a decline in aggregate emissions, whereas a shrinking of the market requires a sufficient degree of substitution towards the $g$-variant if aggregate emissions are to be reduced.

In the light of these findings, concerns raised about potentially perverse effects of environmental labelling, which are based on the presumption that improvements in average environmental performance within the differentiated industry are more than offset by the emission increasing effect of an expanding market (Mattoo and Singh, 1994; Moraga-González and Padrón-Fumero, 1997), are justified only if both variants of the differentiated good are environmentally sensitive vis-à-vis outside consumption. Whether this is the case remains an empirical issue. There seems to be a focus of current labelling policies on industries for which marginal emissions from the traditional $n$-variant are above average and emission reduction is expected for a sufficient degree of substitution towards the $g$-variant (OECD 1991, 1997). However, this falls short from taking into account not only the detrimental effects from a potential market expansion but also the relationship to outside consumption. From an environmental point of view, there may be a case for labelling policies to increase $g$-entry into an environmentally insensitive industry. Enhanced competition would cause a shift of consumption towards this relatively green industry and entail a reduction in aggregate emissions.

## 6. Conclusions

A model of eco-labelling under an imperfect auditing technology has been studied, which integrates asymmetric information on the one hand, and market structure and competitive interaction on the other. The model has shown that the traditional Single crossing property is neither necessary nor sufficient for separation of the market. It may fail to produce an accurate forecast of the actors' reaction to a change in the signal level because it only takes into account the dependency of the actors' incentives on relative profitability between different types. It fails to incorporate the incentives' dependency on absolute profitability, which becomes relevant in the case of endogenous market structure.

The results, as reported in the various propositions, suggest the following. An eco-label may help to promote the establishment of a green industry by resolving the informational asymmetry at least partially and, thereby, overcoming the problem of adverse selection. However, the model identifies a number of cases running counter to the 'intuitive' scenario, in which the lowest separating level of the qualification level maximizes entry of green producers and due to competitive pressure minimizes the non-green supply: An increase in the qualification level may (1) decrease green supply; (2) increase the degree of pooling and; (3) increase aggregate non-green supply.

From welfare analysis, which has been omitted from explicit presentation, follow two implications. Excluding environmental damage from analysis, there are two types of distortions present in the market outcome relative to first best welfare under full information. (1) Asymmetric information reduces welfare directly and indirectly. As an unproductive activity only meant to restore symmetric information auditing directly reduces aggregate consumption, where under perfect competition its cost is fully shifted to consumers. Indirect distortions give rise to too low a level of consumption of the differentiated vis-à-vis the outside good and too low a level of consumption of the high quality vis-à-vis the low quality variant. (2) Entry of a firm causes a negative pecuniary externality by raising average cost of all other firms in the differentiated industry. Thus, the differentiated industry tends to be too large relative to the rest of the economy and its structure is distorted. The indirect distortions due to asymmetric information and the pecuniary externality may partly offset each other, while the direct utility loss due to the restoration of full information is always present. In a second-best setting, in which the labelling agency maximizes consumer utility by choosing an optimal value of the qualification level, it can be shown that the outcome hinges on the impact on the various distortions. In particular, even if there exists a level of the qualification level which maximizes high quality entry and thus surplus from high quality consumption, this may not be welfare optimal because of too great a level of production cost externalities and/or too great an aggregate auditing cost.

Analysis of the environmental impact of labelling has brought to the forefront the importance of recognizing the trade-off between consumption of the differentiated commodity and outside consumption. Environmental labelling may produce a perverse effect, where the improvement of average environmental performance brought about by an increase of $g$-producers' market share is more than offset by the increase in pollution from an expanding market. However, such effect may arise only if both variants of the differentiated good are environmentally sensitive.

The restriction of analysis to general functional forms precludes the deriving of specific solutions. However, the general case provides the most comprehensive overview of potential 'labelling complications'. Any specific problem is readily analyzed by placing the appropriate restrictions on the model. While the model was motivated by the critique of the signalling approaches to eco-labelling which ignore the role of market structure and entry by considering a monopolist, it may fall prey to a parallel critique: Perfect competition seems to be a poor paradigm for addressing the creation of new markets. Further studies should clearly encompass imperfect competition. Moreover, thus far only the screening case has been considered. While this matches a situation in which a central agency issues a type I eco-label, the case of private firm (type II) labels is equally interesting. This requires a signalling approach in which firms actively choose a quality index instead of solely adopting the qualification level of the eco-index.

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# Appendix

## Proofs

**Proposition 3.1:** From (3.1), where $a_j = a_u = 0$, (2.2) and (2.4) follows immediately

$$p_u = C(n, G^*, N^*) < C(g, G^*, N^*) \qquad \forall G^*, N^* .$$

Hence, according to (2.18) $G_u^* = 0$. QED.

**Proposition 3.2:** The proposition is proved by establishing that $\underline{a} < a \le \overline{a}$ is necessary and sufficient for $G^* > 0$. From (2.18) and (3.1) follow the conditions

$$G^* > 0 \Rightarrow C(g, G^*, N^*) + A(g, a) \leq C(n, G^*, N^*) + A(n, a) \quad \text{(A.1)}$$

and

$$G^* > 0 \Leftrightarrow p(G^*, N^*) + \sigma(G^*, N_l{}^*)\varpi(G^*, N^*) \geq C(g, G^*, N^*) + A(g, a) \quad \text{(A.2)},$$

where (A.1) is necessary and (A.2) is necessary and sufficient for $G^* > 0$. From definition (3.2) and for $A_a^n - A_a^g \geq 0$, as by (2.4), follows

$$C(g, 0, N_0) + A(g, a) < C(n, 0, N_0) + A(n, a) \quad \forall a > \underline{a} \ .$$

Hence, (A.1) holds for all $a > \underline{a}$. Moreover, because of $C_G^n < C_G^g$ as by (2.3), condition (A.1) never holds for $a \leq \underline{a}$. Observing that

$$p(G^*, N^*) + \sigma(G^*, N_l{}^*)\varpi(G^*, N^*) \leq C(n, G^*, N^*) + A(n, a); \quad \forall a$$

it follows from definitions (3.3) and (3.2) and $A_a^n - A_a^g \geq 0$ that the condition in (A.2) holds for all $\underline{a} < a \leq \overline{a}$. Thus, $G^* > 0 \Leftrightarrow a^{min} \in \left]\underline{a}, \overline{a}\right]$. QED.

**Proposition 3.3:** Part (i) is immediate from (3.7). Part (ii) is proved as follows. Totally differentiating $n$-type's net revenue from entering the $l$- instead of the $u$-segment, $\pi(n,l) - \pi(n,u)$, with respect to $a^{min}$ yields

$$\frac{d[\pi(n,l) - \pi(n,u)]}{da^{min}} = \sigma_N \varpi \frac{dN_l}{da^{min}} + \varepsilon \frac{dG}{da^{min}} + \sigma \varpi_N \frac{dN}{da^{min}} - A_a^n \quad \text{(A.3)}$$

As $\sigma_N \varpi < 0$ by (2.16), the EWP and, thus the $n$-type's net revenue from entering the $l$- instead of the $u$-segment unambiguously decreases in $N_l{}^*$. Observe that in equilibrium (A.3) must be equal to zero. Then, a positive equilibrium reaction $dN_l / da^{min} = dN_l{}^* / da^{min} > 0$ requires that the aggregate impact on the EWP of changes in $G$ and $N$, as given by the second and third term on the RHS of (A.3), exceed the $n$-type's marginal auditing cost. This is exactly the condition stated in part (ii). Inserting $dG/da^{min} = dG^*/da^{min}$ from (3.7) and $dN/da^{min} = dN^*/da^{min}$ from (3.9) and collecting terms yields

$$\frac{d[\pi(n,l) - \pi(n,u)]}{da^{min}} = \sigma_N \varpi \left[ \frac{dN_l}{da^{min}} - \frac{A_a^n(\alpha\beta - \gamma\delta) - A_a^g(\varepsilon\beta - \sigma\varpi_N \delta)}{|\mathbf{J}|} \right]$$

Comparison with (3.8) shows that the term in brackets gives the derivation of the actual change in labelled $n$-supply from its equilibrium reactivity. Then, $dN_l / da^{min} < 0$ exactly under the conditions given in (3.8), which by reference back to (A.3) imply part (ii) of the proposition. Finally, from (3.8), $(\alpha\beta-\gamma\delta)>0 \Leftarrow dN_l*/da^{min}<0$. Using $dN/dG$, as from total differentiation of (3.4b), $\partial\pi(g,l)/\partial G+(\partial\pi(g,l)/\partial N)(dN/dG)<0 \Leftrightarrow (\alpha\beta-\gamma\delta)>0$, as implied by part (iii) of the proposition, is easily verified. QED.

**Proposition 3.5:** Part (i) is proved as follows. Totally differentiating $g$-profit with respect to $a^{min}$ yields

$$\frac{d\pi(g,l)}{da^{min}}=\alpha\frac{dG}{da^{min}}+(\sigma_N\varpi+\gamma)\frac{dN}{da^{min}}-A_a^g \qquad \text{(A.4).}$$

For $\alpha>0$ ($\alpha<0$) $g$-profit increases (decreases) in $g$-supply. In equilibrium, (A.4) must equal zero. Then, a positive equilibrium reaction $dG/da^{min}=dG*/da^{min}>0$ requires that the net impact on $g$-profit of labelling induced changes in $n$-supply, as given by the second term on the RHS of (A.4) exceed (fall short of) $g$-type's marginal auditing cost in the case of $\alpha<0$ ($\alpha>0$). This conforms to the condition stated in part (i). Inserting $dN/da^{min}=dN*/da^{min}$ from (3.13) and collecting terms yields

$$\frac{d\pi(g,l)}{da^{min}}=\alpha\left[\frac{dG}{da^{min}}-\frac{A_a^g\kappa-A_a^n(\sigma_N\varpi+\gamma)}{|\mathbf{J}'|}\right]$$

Comparison with (3.12) shows that the term in brackets gives the derivation of the actual change in $g$-supply from its equilibrium reactivity. Evidently, $dG/da^{min}>0$ exactly under the conditions given in (3.12) which by reference back to (A.4) imply part (i) of the proposition. Part (ii) is proved by analogy. Observing the inequalities in (3.10) one sees immediately from (3.12) that $dG*/da^{min}>0 \Rightarrow \partial\pi(g,l)/\partial N=\sigma_N\varpi+\gamma<0$ and from (3.13) that $dN*/da^{min}<0 \Leftarrow \partial\pi(g,l)/\partial G=\alpha<0$ as stated in part (iii). QED.

**Proposition 5.1:** We obtain from (4.5) for $\zeta\to 0$

$$\frac{dE}{da^{min}}<0 \Leftrightarrow \frac{dN*}{da^{min}}\begin{Bmatrix}\leq\\>\end{Bmatrix}-\frac{E_G+E_m\,\partial m/\partial G}{E_N+E_m\,\partial m/\partial N}\frac{dG*}{da^{min}} \text{ if } E_N+E_m\,\partial m/\partial N\begin{Bmatrix}\geq\\<\end{Bmatrix}0 \qquad \text{(A.5).}$$

By (3.7), $dG*/da^{min}>0$ for regime 1. For regime 2, it follows from (3.11a) and (3.11b) as required by stability and under observation of the inequalities in (3.10) that

$$dN*/da^{min}\begin{Bmatrix}>\\<\end{Bmatrix}0\begin{Bmatrix}\Rightarrow\\\Leftarrow\end{Bmatrix}dG*/da^{min}\begin{Bmatrix}>\\<\end{Bmatrix}0 \qquad \text{(A.6)}$$

When observing $dG^*/da^{min} > 0$ for and (A.6) for regime 1 and 2, respectively, together with definition 5.1, the conditions for the various cases as given in the proposition are easily derived from (A.5). QED.

**Abbreviations and Notation**

EWP: expectations weighted premium
MRS: marginal rate of substitution
SCP: single crossing property

| | |
|---|---|
| $A(\theta, a), \quad \theta = g, n$ | type specific average auditing cost |
| $A_a^\theta, \quad \theta = g, n$ | type specific marginal change in average auditing cost with respect to index-value (= marginal auditing cost) |
| $a \in [0, a^{max}]$ | (eco-) quality index |
| $a^{min}$ | minimum quality index associated with the label (labelling requirement) |
| $\underline{a}, \overline{a}$ | upper and lower boundary value with regard to $a^{min}$ in between which green entry occurs |
| $C(\theta, G, N), \quad \theta = g, n$ | type specific average cost |
| $C_G^g; C_G^n; C_N^n; C_N^g$ | marginal change of type specific average cost in aggregate output of green and non-green firms, respectively |
| $E$ | aggregate emission level |
| $E_N, E_G, E_m$ | marginal emissions from the non-green, green, and outside good, respectively |
| $G$, $G^D$ | aggregate output of green-firms; expected consumption of the green variant |
| $I$ | income |
| $i = 1,2,\ldots, M$ | index of firms |
| $j = l, u$ | index of market segment with and without label, respectively |
| $\Gamma$ | number of green firms |
| $\Lambda$ | number of non-green firms |
| $M = \Gamma + \Lambda$ | aggregate number of firms |

| | |
|---|---|
| $m$ | composite outside consumption |
| $N$, $N^D$ | aggregate output of non-green firms; expected consumption of the non-green variant |
| $p$ | baseline price = MRS between differentiated and outside good with respect to pure consumption |
| $p_G, p_N$ | first derivative of baseline price with regard to aggregate output of green and non-green firms, respectively |
| $p_j$, $j = l, u$ | price in segment $j$ |
| $\pi$ | profit |
| $Q_j^S$; $j = l, u$ | aggregate supply in segment $j$ |
| $q(\theta)$, $\theta = g, n$ | type specific capacity |
| $\theta \in \{g, n\}$ | quality type (green or non-green) |
| $\sigma_j$ | expected share of the green variant in aggregate supply of segment $j$ |
| $\sigma_G^j, \sigma_N^j$, $j = l, u$ | first derivative of $\sigma_j$ with regard to aggregate output of green and non-green firms, respectively |
| $U$ | utility |
| $v$ | extra private benefit from green consumption |
| $v'$, $v''$ | first and second derivatives of sub-utility $v$ |
| $\varpi$ | premium = MRS between extra-benefit and marginal utility of pure consumption of the outside commodity |
| $\varpi_G, \varpi_N$ | first derivative of the premium with regard to aggregate output of green and non-green firms, respectively |
| $w$ | sub-utility from pure consumption |
| $w_1, w_m$ | first derivatives of sub-utility $w$ with respect to first and second argument |
| $w_{11}, w_{mm}, w_{1m}, w_{m1}$ | second derivatives of sub-utility $w$ with respect to first and second argument |