ETHICS, WELFARE AND MARKETS

Abstract

The present paper examines society's welfare when goods with identical physical attributes can be produced using two alternative technologies, one of them less ethically desirable but less expensive for at least some producers. For the scenario where identification costs *must* be borne by producers and consumers of the high-quality good, the outcome under unregulated markets is isomorphic to the central planner's optimal solution. However, under certain circumstances the unregulated market equilibrium may be improved upon by government intervention that shifts the burden of identification costs to the producers of the low quality good, or which bans the production of the low quality good. The optimal intervention needs to be determined case-by-case and depends on consumer preferences, relative production costs, and relative costs of identification and fraud prevention.

Keywords: certification, ethical trade, identity preservation, segregation, welfare.

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ETHICS, WELFARE AND MARKETS

Should society allow the sale of goods produced with child labor or with other similarly distasteful production technologies? So long as the child laborer and the ultimate consumer participate on a voluntary and fully informed basis, it would seem that welfare can only increase when these products are sold. If these goods are to be allowed, should government mandate their segregation? Should the producers and consumers of child labor bear the cost of certification, or should this be borne by the producers and consumers of non-child labor products?

The issue described above is of importance because increasing affluence and globalization has allowed consumers in some countries to pay more attention to the ethical aspects of production processes, even where the production practices do not change the objective physical nature of the resulting products. Examples include dolphin-safe tuna, genetically modified (GM) crops, humanely treated animals, conflict diamonds, goods produced with child or prison labor, and lumber from rainforests and/or virgin growth. This issue is of recent relevance because the European Union (EU) and the U.S. have responded in different ways in an ongoing dispute at the World Trade Organization, with the EU generally in favor of allowing certification to be used as a form of trade restriction and imposing segregation costs on the goods produced with undesirable technologies (Mahe; Tallontire and Blowfield).

There is an existing literature on credence goods that allows for a positive or negative impact on the ultimate quality of the good but where the consumer cannot differentiate it at the time of purchase (Darby and Karni; Leland; Wolinsky; Nitzan and Tzur; Pitchik and Schotter (1987, 1993)). There is also a literature on production practices that impart positive ethical attributes such as with an eco-label (Bagnoli and Watts, Kirchhoff, Grolleau, and Nimon and Beghin (1999a, 1999b)). Dulleck and Kerschbamer, and Crespi and Marette provide respective reviews of the credence goods and eco-label literature.

We are interested in production processes that are distasteful to some consumers but which otherwise do not impact on the quality of the product, and which can be employed at lower cost by some producers. In order to expand the definition to include these production practices, we use the terms "undesirable technology" and "desirable technology" to indicate whether the production process adds or subtracts ethical value. To focus on these ethical issues, we do not incorporate or examine the impact of fraud or market power.

To the best of our knowledge, the literature has not examined the market and welfare outcomes when goods and production practices have negative ethical characteristics. One of our first results helps explain the paucity of research in this area. The decentralized competitive market equilibrium will never lead to a situation where goods produced with the undesirable technology are voluntarily identified. This means that the labels that exist are always of the positive type, and it explains why the eco-label literature has tracked these positive labels. We show that is instructive to broaden the definition to include negative ethical characteristics. This is true because when one acknowledges that less desirable production practices also exist, one can find outcomes under government intervention that improve upon the decentralized market outcome, provided regulatory costs are sufficiently low.

Although we do not want to describe GM crops as having negative ethical characteristics, there is a similarity with the rich literature on the welfare effects of introducing GM grains (Fulton and Giannakas; Lapan and Moschini; Lence and Hayes (2005, 2006); Furtan, Gray, and Holzman; Giannakas and Fulton; and most recently Giannakas and Yiannaka). Our model follows the structure of Giannakas and Yiannaka in that we allow for a heterogeneous consumers response and a heterogeneous producer benefit.

To see how this market failure might occur, consider a stylized example based on Lence and Hayes (2006). Suppose that a great majority of households in the EU are willing to pay a premium to avoid consumption of GM grains. Suppose also that a small number of farmers in the EU find it profitable to produce these grains and that it is legal for them to do so. Once this GM grain is harvested it will be co-mingled with non-GM grain and consumers will have to assume that all commodity grain is GM. If these consumers wish to purchase non-GM grain they will need to pay the costs associated with a new grain handling and transporting system. This alternative system will be relatively expensive because it will need to be able to maintain the identity of the product and because the existing bulk handling facilities will be in use for the GM grain. If the total additional costs associated with the new system exceed the savings made by those producers who adopt GM crops, then societal welfare will fall. Consumers who prefer non-GM grain will lose, either because they are forced to pay additional costs or because they consume GM grain at a discount to non-GM grain. Producers who do not produce GM grain and who do not participate in the niche market lose because GM grain prices fall. In these circumstances, it may make sense to ban production and imports of GM grains, or to require segregation of GM grains so that the bulk handling system can be utilized for non-GM grains, provided the costs of such regulations are not too high. A similar set of arguments could be used to motivate the segregation of livestock products from cloned animals.

The purpose of this paper is to examine the welfare aspects and uniqueness of the outcomes under both the free market equilibrium and the optimal solution to the central planner's problem. We differentiate among consumers so that they have unique preferences for and against the two technologies, and we differentiate among producers so that they face different production costs for both types of technologies.

The unregulated market equilibrium will always result in certification costs being added to the production costs under the desirable technology, so that a niche market in the "high-quality" good will evolve as needed. This market situation may occur even if the majority of consumers strictly prefer the high-quality good and the cost savings from the undesirable technology are negligible.[1] If certification of the desirable technology output is assumed to be the only way to identify the high-quality good, then the market outcome is the same as the central planner's optimal solution. However, the government has several other solutions at its disposal to improve upon the non-intervention market outcome. It can simply ban the undesirable

[1]Note that the presence of a labeled high quality good does not always imply that non-labeled goods are low quality. For example, if some furniture is labeled as child-labor free, it does not mean that all non-labeled furniture is made with child labor.

technology, thereby eliminating all costs associated with certification of the high-quality good (albeit at the cost of enforcing the ban). Alternatively, it can require the output from the undesirable technology to be segregated and labeled (for which it will incur costs to prevent fraud), thereby shifting identification costs to those who participate in the market for low-quality good. Our contribution consists of exploring the circumstances under which the unregulated market equilibrium is the same as the central planner's optimal solution, and those under which it can be improved upon by different kinds of government intervention.

Under standard assumptions about consumer preferences and relative production costs, societal welfare under some of the regulated outcomes is higher than under the non-intervention market outcome if regulatory costs are sufficiently low. The intuition is that producers employing the undesirable technology have no incentive to certify their output as such, and the market has no way to induce them to do so. This means that participants in the high-quality good market always bear the identification costs, regardless of the relative size of this market or the relative costs of certification. These additional certification costs act like a tax on the system and can result in lower welfare outcomes than might exist if the undesirable technology were banned or its output were subject to mandatory segregation.

We begin with a description of consumers, producers and the market and welfare-maximizing outcomes in the case where identification costs are borne by the producers and consumers of the high-quality good. We show that the social planner's optimal solution for this scenario is isomorphic to the outcome that would naturally emerge under unregulated markets. We then introduce two alternative methods for allocating identification costs that are available to regulators but which will not emerge from unregulated markets. The first is an outright ban on the undesirable technology, and the second is the allocation of identification costs to producers and consumers of the undesirable technology. We then show the welfare-maximizing outcomes under a range of parameterizations and define the circumstances under which intervention increases welfare relative to the unregulated market equilibrium.

1. Consumers

The economy is assumed to be inhabited by an infinite number of consumers, whose only difference is the value of a parameter δ representing their relative distaste for goods produced in a way that some consumers consider unethical or undesirable. The total population of consumers is normalized to have unitary mass, and the distribution of consumers is denoted by the differentiable cumulative density function (cdf) $F_D(\delta)$ with support $[\underline{\delta}, \bar{\delta}\,]$, where $\underline{\delta} \geq 0$.

Following Lancaster and Becker, goods available for consumption are assumed to consist of bundles of "characteristics," and the utility function of consumers is defined in terms of such characteristics rather than the goods themselves. The utility function of a consumer of type δ is given by $u = z_0 + v(z_G) - \delta z_B$, where v is a differentiable function with $v' > 0$, $v'' < 0$, and $lim_{z \to 0} v'(z) = \infty$. Variable z_0 is a numeraire characteristic, z_G is a "good" characteristic (i.e., it enhances utility), whereas z_B is a "bad" characteristic (i.e., it exerts disutility). Parameter $\delta \geq 0$ measures the consumer's disutility associated with characteristic z_B; consumers with $\delta = \delta^{\circ}$ dislike characteristic z_B more (less) strongly than consumers with $\delta <$ (>) δ°. For the present purposes, the essential features of the assumed utility function u are quasilinearity and separable linearity in z_B. Quasilinearity allows us to restrict attention to partial equilibrium analysis (e.g., Mas-Colell, Whinston, and Green, p. 319), whereas separable linearity in z_B renders parameter δ easy to interpret in monetary terms.

Goods available for consumption are of three types, namely, a numeraire good x_0 that yields one unit of characteristic z_0, a high-quality good x_H that yields one unit of characteristic z_G, and a low-quality good x_L that yields one unit of both characteristic z_G and the bad characteristic z_B. A crucial assumption for the present purposes is that goods x_H and x_L are physically identical to the consumer even after having consumed them, except for documentation attached to x_H certifying that it does not contain the bad characteristic z_B.

Goods x_H and x_L are meant to represent pairs of goods such as dolphin-safe tuna vs. regular tuna. The difference between goods x_H and x_L can be best understood as arising not from the goods' actual physical properties, but from the technology used to produce them instead.

Thus, good x_H results from a technology that consumers deem more desirable (e.g., because of its lower environmental impact, or the more humane conditions for workers, etc.) together with the necessary documentation to permit verification of the claim that it was obtained by means of such technology. The low-quality good x_L lacks the documentation required to verify that was produced using the desirable technology. This may happen because x_L is either the outcome of the undesirable technology, or it is obtained under the desirable technology without furnishing the appropriate documentation to enable verification. Importantly, since the model satisfies Dulleck and Kerschbamer's verifiability assumption, consumers cannot be charged for the high-quality good when in fact they receive the low-quality one.

Consumers face the standard budget constraint $W = x_0 + P_H\, x_H + P_L\, x_L$, where W denotes the consumer's wealth and P_H (P_L) represents the price of good x_H (x_L). Substituting the budget constraint and the characteristics in terms of available goods into utility function u yields:

(1.1) $$U = W + v(x_H + x_L) - P_H\, x_H - (P_L + \delta)\, x_L.$$

Function U is strictly concave in x_H and x_L, and strictly concave in ($x_H + x_L$) when $P_H = P_L + \delta$. Hence, there is either a unique pair [x_H^*, x_L^*] (if $P_H \neq P_L + \delta$) or sum $(x_H^* + x_L^*)$ (if $P_H = P_L + \delta$) that maximizes U globally. The first-order necessary conditions for maximization (FOCs) are:

(1.2) $$\frac{\partial U^*}{\partial x_H} = -\,P_H + v'(x_H^* + x_L^*) \leq 0,\; x_H^* \geq 0,\; x_H^* \frac{\partial U^*}{\partial x_H} = 0,$$

(1.3) $$\frac{\partial U^*}{\partial x_L} = -\,(P_L + \delta) + v'(x_H^* + x_L^*) \leq 0,\; x_L^* \geq 0,\; x_L^* \frac{\partial U^*}{\partial x_L} = 0.$$

FOCs (1.2) and (1.3) imply that the optimal amounts of the high- and low-quality goods purchased by a consumer of type δ depend on the difference between their respective prices. Since $\partial U^*/\partial x_L - \partial U^*/\partial x_H = P_H - (P_L + \delta)$, it follows that $\partial U^*/\partial x_H$ cannot be binding at the optimum if $P_H > P_L + \delta$. Hence, when $P_H - P_L > \delta$, demands for the high- and low-quality goods by a δ-type consumer are $x_{H,\delta} = 0$ and $x_{L,\delta} = v'^{-1}(P_L + \delta)$, respectively. Following a similar argument, when $P_H - P_L < \delta$ the respective demands are given by $x_{H,\delta} = v'^{-1}(P_H)$ and $x_{L,\delta} = 0$. Finally, when $P_H - P_L = \delta$, an agent of type δ is indifferent between consuming (a) $v'^{-1}(P_L + \delta)$ units of the low-quality good and no high-quality good, or (b) no low-quality good and $v'^{-1}(P_H)$ units of the high-quality good, or (c) any convex combination of bundles (a) and (b).

Substituting the optimal consumption quantities back into (1.1) yields the indirect utility for a consumer of type δ:

(1.4) $\quad V = W + v[v'^{-1}(P_\delta)] - P_\delta\, v'^{-1}(P_\delta),$

where $P_\delta \equiv min(P_H, P_L + \delta)$ represents the "full" price for the bundle of non-numeraire goods for a consumer of type δ. From (1.4), it can be seen that parameter δ is essentially a surcharge on the price of the low-quality good paid by an agent of type δ, effectively reducing its desirability vis-à-vis the high-quality good. Consuming one unit of the low-quality good acts like imposing a cost of δ on a consumer of type δ; hence, he will prefer the low-quality good over the high-quality one only if the total cost of the former ($P_L + \delta$) is smaller than the cost of the latter (P_H), and vice versa. It follows from Roy's Identity that the demand for the bundle of non-numeraire goods is given by $-(\partial V/\partial P_\delta)/(\partial V/\partial W) = v'^{-1}(P_\delta)$.

2. Producers

Producers can use either the desirable or the undesirable technology to produce goods. Costs depend only on the total amount of output, except in that production under the desirable (undesirable) technology for firms with $\sigma > (\leq)\ 0$ increases costs by $\sigma\,(|\sigma|)$ per unit for σ-type firms,[2] and furnishing the necessary documentation to verify that the good was produced under the desirable technology costs $I_{cer} \equiv I \geq 0$ per unit. Such certification enables producers to sell the desirable technology output as high-quality good. Lacking such certification, the desirable technology output can only be sold as low-quality good. Mirroring the consumption side of the

[2]GM crops represents a real world example of a situation where producing under the undesirable technology increases costs for some firms. This is true because some farmers have reported lower yields for GM crops (e.g., Roundup Ready soybeans) compared to conventional varieties. However, the typical situation is characterized by higher costs associated with the desirable technology.

economy, the production sector is normalized to have mass one and is assumed to consist of an infinite number of producers who only differ by parameter σ. The distribution of producers is represented by the differentiable cdf $F_S(\sigma)$ with support $[\underline{\sigma}, \overline{\sigma}]$.

Profits for a producer of type σ are given by (2.1):

$$\text{(2.1)} \quad \pi = P_H\, x_h + P_L\,(x_{\not h} + x_l) - [c(x_h + x_{\not h} + x_l) + I\, x_h + \iota_{\sigma>0}\, \sigma\,(x_h + x_{\not h}) - \iota_{\sigma\leq 0}\, \sigma\, x_l],$$

where x_h denotes certified output from the desirable technology, $x_{\not h}$ represents output from the desirable technology but without certification, x_l is output from the undesirable technology, and c is a differentiable variable cost function satisfying $c(0) = 0$, $c' > 0$, $c'' > 0$, and $lim_{x\to 0}c'(x) = 0$. The indicator function $\iota_{\sigma>0}$ ($\iota_{\sigma\leq 0}$) equals one if $\sigma >$ ($\leq$) 0, and zero otherwise. The term within brackets is the production cost for a firm of type σ. If $P_H - I - \sigma \neq P_L$, profit function π is strictly concave in x_h, $x_{\not h}$, and x_l, so there is a unique triplet $[x_h^*, x_{\not h}^*, x_l^*]$ that maximizes it globally. When $P_H - I - \sigma = P_L$, π is strictly concave in either $(x_h + x_l)$ if $\sigma \neq 0$ or $(x_h + x_{\not h} + x_l)$ if $\sigma = 0$, and there is a unique set $[x_h^* + x_{\not h}^*,\ x_l^*]$ or $[x_h^* + x_{\not h}^* + x_l^*]$, respectively, that globally maximizes π.

The FOCs for maximization of (2.1) are:

$$\text{(2.2)} \quad \frac{\partial \pi^*}{\partial x_h} = P_H - c'(x_h^* + x_{\not h}^* + x_l^*) - I - \iota_{\sigma>0}\,\sigma \leq 0,\ x_h^* \geq 0,\ x_h^*\, \frac{\partial \pi^*}{\partial x_h} = 0,$$

$$\text{(2.3)} \quad \frac{\partial \pi^*}{\partial x_{\not h}} = P_L - c'(x_h^* + x_{\not h}^* + x_l^*) - \iota_{\sigma>0}\,\sigma \leq 0,\ x_{\not h}^* \geq 0,\ x_{\not h}^*\, \frac{\partial \pi^*}{\partial x_{\not h}} = 0,$$

$$\text{(2.4)} \quad \frac{\partial \pi^*}{\partial x_l} = P_L - c'(x_h^* + x_{\not h}^* + x_l^*) + \iota_{\sigma\leq 0}\,\sigma \leq 0,\ x_l^* \geq 0,\ x_l^*\, \frac{\partial \pi^*}{\partial x_l} = 0.$$

FOCs (2.3) and (2.4) imply that $\partial\pi^*/\partial x_{\not h}$ cannot bind at the optimum if $\sigma > 0$, in which case $x_{\not h}^* = 0$. In this instance, whether the firm prefers to produce x_h or x_l depends on the magnitudes of the respective prices. If $P_H - I - \sigma > P_L$, profits are maximized with $x_h^* = c'^{-1}(P_H - I - \sigma)$ and $x_l^* = 0$; otherwise, the firm is better off producing $x_h^* = 0$ and $x_l^* = c'^{-1}(P_L)$. Similarly, $x_l^* = 0$ if $\sigma < 0$, because in such instance $\partial\pi^*/\partial x_h$ cannot bind at the optimum. When $\sigma < 0$ (i.e., producing under the undesirable technology increases costs), FOCs (2.2) and (2.3) imply that optimal output consists of [x_h^*, x_h^*] = [$c'^{-1}(P_H - I)$, 0] ([0, $c'^{-1}(P_L)$]) if $P_H - I > (<)\ P_L$.

Upon simplification, plugging FOCs back into (2.1) yields the profit function (2.5):

(2.5) $\Pi = P_\sigma\, c'^{-1}(P_\sigma) - c[c'^{-1}(P_\sigma)]$.

Price $P_\sigma \equiv max(P_H - I - \iota_{\sigma>0}\ \sigma, P_L)$ represents the "full" price for a producer of type σ. From Hotelling's Lemma, such a producer's supply is given by $\partial\Pi/\partial P_\sigma = c'^{-1}(P_\sigma)$.

3. Market Equilibrium

Aggregate demand functions for the high- and low-quality goods are obtained by integrating individual demands across consumer types:

(3.1) $X_{H,D} = \int_{P_H - P_L}^{\bar{\delta}} v'^{-1}(P_H)\ dF_D(\delta)$,

(3.2) $X_{L,D} = \int_{\underline{\delta}}^{P_H - P_L} v'^{-1}(P_L + \delta)\ dF_D(\delta)$.

Similarly, aggregate supply functions of certified and uncertified goods under the desirable technology, and supply functions of goods produced using the undesirable technology are obtained by integrating individual supplies across producer types:

(3.3) $X_{h,S} = \begin{cases} \int_{\underline{\sigma}}^{P_H - P_L - I} c'^{-1}(P_H - I - \iota_{\sigma\rangle 0}\sigma)\, dF_S(\sigma) & \text{if } P_H - P_L - I \geq 0, \\ 0 \text{ otherwise.} \end{cases}$

(3.4) $X_{\hbar,S} = \begin{cases} \int_{\underline{\sigma}}^{0} c'^{-1}(P_L)\, dF_S(\sigma) & \text{if } P_H - P_L - I \leq 0, \\ 0 \text{ otherwise.} \end{cases}$

(3.5) $X_{l,S} = \begin{cases} \int_{max(0, P_H \text{-} P_L \text{-} I)}^{\bar{\sigma}} c'^{-1}(P_L)\, dF_S(\sigma), \\ 0 \text{ otherwise.} \end{cases}$

Letting $ES_H \equiv X_{h,S} - X_{H,D}$ and $ES_L \equiv X_{\hbar,S} + X_{l,S} - X_{L,D}$ denote excess supplies of high- and low-quality goods, respectively, and superscript "*eq*" identify equilibrium attained by market clearing, equilibrium prices P_H^{eq} and P_L^{eq} are determined by the market-clearing conditions:

(3.6) High-quality good: $ES_H^{eq} \geq 0,\ P_H^{eq} \geq 0,\ P_H^{eq}\ ES_H^{eq} = 0,$

(3.7) Low-quality good: $ES_L^{eq} \geq 0,\ P_L^{eq} \geq 0,\ P_L^{eq}\ ES_L^{eq} = 0.$

Prices P_H^{eq} and P_L^{eq} depend on consumers' preferences v, producers' cost function c, consumers' distaste for the low-quality good (i.e., $F_D(\delta)$), producers' savings from using the undesirable technology (i.e., $F_S(\sigma)$), and certification costs I. It will be shown in the next section that, under the stated assumptions, a market equilibrium exists, is unique, and is identical to the social planner's optimal solution.

4. The Central Planner's Solution

To analyze some of the important properties of the market equilibrium outcome, the model is recast as the problem of a central planner whose objective is to choose the individual amounts consumed and produced so as to maximize a social welfare function, subject to the constraint that aggregate consumption does not exceed aggregate output for each type of good. Given a social welfare function attaching identical weight to each individual consumer and producer, the planner's optimization problem consists of:

$$\text{(4.1)} \quad \max_{\{x_{H,\delta}, x_{L,\delta}, x_{h,\sigma}, x_{\hbar,\sigma}, x_{l,\sigma}, \mu_H, \mu_L\} \forall \delta \in [\underline{\delta}, \bar{\delta}] \text{ and } \sigma \in [\underline{\sigma}, \bar{\sigma}]} \Omega_{cer} = W + \int_{\underline{\delta}}^{\bar{\delta}} [v(x_{H,\delta} + x_{L,\delta}) - \delta x_{L,\delta}]\, dF_D(\delta)$$

$$- \int_{\underline{\sigma}}^{\bar{\sigma}} [c(x_{h,\sigma} + x_{\hbar,\sigma} + x_{l,\sigma}) + I x_{h,\sigma} + \iota_{\sigma>0}\sigma(x_{h,\sigma} + x_{\hbar,\sigma}) - \iota_{\sigma\leq 0}\sigma x_{l,\sigma}]\, dF_S(\sigma)$$

$$+ \mu_H \left[\int_{\underline{\sigma}}^{\bar{\sigma}} x_{h,\sigma}\, dF_S(\sigma) - \int_{\underline{\delta}}^{\bar{\delta}} x_{H,\delta}\, dF_D(\delta) \right]$$

$$+ \mu_L \left[\int_{\underline{\sigma}}^{\bar{\sigma}} x_{\hbar,\sigma}\, dF_S(\sigma) + \int_{\underline{\sigma}}^{\bar{\sigma}} x_{l,\sigma}\, dF_S(\sigma) - \int_{\underline{\delta}}^{\bar{\delta}} x_{L,\delta}\, dF_D(\delta) \right],$$

where μ_H and μ_L are the lagrangian multipliers corresponding to the aggregate amounts of high- and low-quality goods, respectively. The FOCs for consumers of type δ are:

$$(4.2)\qquad \frac{\partial \Omega^*_{cer}}{\partial x_{H,\delta}} = -\ \mu_H^{cer} + v'(x^{cer}_{H,\delta} + x^{cer}_{L,\delta}) \leq 0,\ x^{cer}_{H,\delta} \geq 0,\ x^{cer}_{H,\delta}\ \frac{\partial \Omega^*_{cer}}{\partial x_{H,\delta}} = 0,$$

$$(4.3)\qquad \frac{\partial \Omega^*_{cer}}{\partial x_{L,\delta}} = -\,(\mu_L^{cer} + \delta) + v'(x^{cer}_{H,\delta} + x^{cer}_{L,\delta}) \leq 0,\ x^{cer}_{L,\delta} \geq 0,\ x^{cer}_{L,\delta}\ \frac{\partial \Omega^*_{cer}}{\partial x_{L,\delta}} = 0.$$

Similarly, FOCs for each producer of type σ are:

$$(4.4)\qquad \frac{\partial \Omega^*_{cer}}{\partial x_{h,\sigma}} = \mu_H^{cer} - c'(x^{cer}_{h,\sigma} + x^{cer}_{\hbar,\sigma} + x^{cer}_{l,\sigma}) - I - \iota_{\sigma>0}\,\sigma \leq 0,\ x^{cer}_{h,\sigma} \geq 0,\ x^{cer}_{h,\sigma}\ \frac{\partial \Omega^*_{cer}}{\partial x_{h,\sigma}} = 0,$$

$$(4.5)\qquad \frac{\partial \Omega^*_{cer}}{\partial x_{\hbar,\sigma}} = \mu_L^{cer} - c'(x^{cer}_{h,\sigma} + x^{cer}_{\hbar,\sigma} + x^{cer}_{l,\sigma}) - \iota_{\sigma>0}\,\sigma \leq 0,\ x^{cer}_{\hbar,\sigma} \geq 0,\ x^{cer}_{\hbar,\sigma}\ \frac{\partial \Omega^*_{cer}}{\partial x_{\hbar,\sigma}} = 0,$$

$$(4.6)\qquad \frac{\partial \Omega^*_{cer}}{\partial x_{l,\sigma}} = \mu_L^{cer} - c'(x^{cer}_{h,\sigma} + x^{cer}_{\hbar,\sigma} + x^{cer}_{l,\sigma}) + \iota_{\sigma\leq 0}\,\sigma \leq 0,\ x^{cer}_{l,\sigma} \geq 0,\ x^{cer}_{l,\sigma}\ \frac{\partial \Omega^*_{cer}}{\partial x_{l,\sigma}} = 0.$$

Finally, the FOCs with respect to the lagrangian multipliers are:

$$(4.7)\qquad \frac{\partial \Omega^*_{cer}}{\partial \mu_H} = \int_{\underline{\sigma}}^{\bar{\sigma}} x^{cer}_{h,\sigma}\, dF_S(\sigma) - \int_{\underline{\delta}}^{\bar{\delta}} x^{cer}_{H,\delta}\, dF_D(\delta) \geq 0,\ \mu_H^{cer} \geq 0,\ \mu_H^{cer}\ \frac{\partial \Omega^*_{cer}}{\partial \mu_H} = 0,$$

$$(4.8)\qquad \frac{\partial \Omega^*_{cer}}{\partial \mu_L} = \int_{\underline{\sigma}}^{\bar{\sigma}} x^{cer}_{\hbar,\sigma}\, dF_S(\sigma) + \int_{\underline{\sigma}}^{\bar{\sigma}} x^{cer}_{l,\sigma}\, dF_S(\sigma) - \int_{\underline{\delta}}^{\bar{\delta}} x^{cer}_{L,\delta}\, dF_D(\delta) \geq 0,\ \mu_L^{cer} \geq 0,\ \mu_L^{cer}\ \frac{\partial \Omega^*_{cer}}{\partial \mu_L} = 0.$$

Given that the social welfare function is strictly quasiconcave and that the constraint set is convex, there is a unique global constrained maximizer to the social planner's problem (e.g., Mas-Colell, Whinston, and Green, p. 962).

Upon relabeling P_H and P_L as μ_H and μ_L, respectively, the conditions underlying the market equilibrium (i.e., (1.2), (1.3), (2.2), (2.3), (2.4), (3.6), and (3.7)) are clearly the same as the conditions for the social planner's optimum. This proves Proposition 1.

Proposition 1: Under the assumptions about consumers and producers stated in Sections 1 and 2, a market equilibrium exists, is unique, and is identical to the social planner's optimal solution.

Letting Ω_{cer}^{eq} denote the value of the social welfare function under market equilibrium, Proposition 1 implies that $\Omega_{cer}^{eq} = \Omega_{cer}^{*}$. Another property of the market equilibrium that will be useful later in the proof of Proposition 3 is summarized as Proposition 2.

Proposition 2: Under the assumptions about consumers and producers stated in Sections 1 and 2, the market equilibrium is characterized by $X_{H,D}^{eq} = X_{h,S}^{eq}$ and $X_{L,D}^{eq} = X_{l,S}^{eq} + X_{\hbar,S}^{eq}$.

Proof: Note that $X_{H,D}^{eq} = X_{h,S}^{eq}$ is equivalent to $\partial\Omega_{cer}^{*} / \partial\mu_H = 0$ in (4.7). Assume on the contrary that $\partial\Omega_{cer}^{*} / \partial\mu_H \neq 0$. Since $\partial\Omega_{cer}^{*} / \partial\mu_H < 0$ is ruled out by the first term in (4.7), it must be the case that $\partial\Omega_{cer}^{*} / \partial\mu_H > 0$, in which case $\mu_H^{cer} = 0$ by the last term in (4.7). But if $\mu_H^{cer} = 0$, the first integral making up $\partial\Omega_{cer}^{*} / \partial\mu_H$ must be zero by (4.4). This implies that the second integral in $\partial\Omega_{cer}^{*} / \partial\mu_H$ must be strictly negative, which contradicts the non-negativity restriction in (4.2). An analogous argument can be used to prove that $\partial\Omega_{cer}^{*} / \partial\mu_L = 0$ in (4.8), which is equivalent to $X_{L,D}^{eq} = X_{l,S}^{eq} + X_{\hbar,S}^{eq}$. □

5. Properties of Society's Value Function under Market Equilibrium

Society's value function under market equilibrium Ω_{cer}^{eq}, consumption ($X_{H,D}^{eq}$ and $X_{L,D}^{eq}$), and production ($X_{h,S}^{eq}$, $X_{\hbar,S}^{eq}$, and $X_{l,S}^{eq}$) are all affected in a major way by certification costs (*I*). The main properties of Ω_{cer}^{eq}, $X_{H,D}^{eq}$, $X_{L,D}^{eq}$, $X_{h,S}^{eq}$, $X_{\hbar,S}^{eq}$, and $X_{l,S}^{eq}$ regarding certification costs are summarized in Proposition 3:

Proposition 3: Under the assumptions about consumers and producers stated in Sections 1 and 2, society's value function, aggregate consumption, and aggregate production under market equilibrium exhibit the following properties regarding the certification cost parameter *I*:

a. $\partial\Omega_{cer}^{eq} / \partial I = -X_{h,S}^{eq}$.
b. If $I >$ (<) $\bar{\delta} - max(0, \underline{\sigma})$: $\partial^2\Omega_{cer}^{eq} / \partial I^2 =$ (>) 0, $X_{H,D}^{eq} = X_{h,S}^{eq} =$ (>) 0.

c. If $I < \overline{\delta}$ or $\underline{\sigma} > 0$: $X_{h,S}^{eq} = 0$; if $I > \overline{\delta}$ and $\underline{\sigma} < 0$: $X_{h,S}^{eq} > 0$.

d. If $I <(>)\ \underline{\delta} - \overline{\sigma}$: $X_{L,D}^{eq} = (>)\ 0$, $X_{l,S}^{eq} = (>)\ 0$.

Proof: 3.a follows from application of the envelope theorem (e.g., Mas-Colell, Whinston, and Green, p. 964), which yields $\partial \Omega_{cer}^{*} / \partial I = - \int_{\underline{\sigma}}^{\overline{\sigma}} x_{h,\sigma}^{cer}\, dF_S(\sigma) \equiv - X_{h,S}^{cer} = - X_{h,S}^{eq}$. The proofs of 3.b, 3.c, and 3.d are shown in Appendix A. □

Proposition 3 is summarized pictorially on the right-hand orthants of Figures 1 through 3. We will be using these figures for other analysis later in the paper and they therefore contain more notation than needed at present. For now, just focus on the right-hand side of the figures and pay attention to the solid lines. Figure 1 depicts the case where the minimum dislike cost associated with the low-quality good exceeds the maximum additional cost from the desirable technology (i.e., $\underline{\delta} > \overline{\sigma}$). In this scenario, when certification costs are sufficiently small, the minimum premium that consumers are willing to pay for the high-quality good exceeds the maximum reward required to induce the use of the desirable technology and certify the good, therefore aggregate consumption consists entirely of high-quality good. Such a situation occurs when $0 < I < \underline{\delta} - \overline{\sigma}$. The other polar scenario arises when certification costs are so high that the maximum premium consumers are willing to pay for the high-quality good is not enough to cover the minimum premium required by producers to use the desirable technology and certify (i.e., $I > \overline{\delta} - max(0, \underline{\sigma})$). In this instance, aggregate consumption will only be made of low-quality good (from the undesirable technology, and/or from the desirable technology without certification). At intermediate certification costs (i.e., $\underline{\delta} - \overline{\sigma} < I < \overline{\delta} - max(0, \underline{\sigma})$), aggregate consumption of both high- and low-quality good is strictly positive. The high-quality (low-quality) good is supplied by producers with relatively small (large) σ and consumed by agents with relatively large (small) δ.

In Figure 1, the value functions $\Omega_{cer}^{eq} = \Omega_{cer}^{*}$ are declining in the certification cost parameter I as long as aggregate supply of the high-quality good is strictly positive. Once

Figure 1. Social welfare functions when the undesirable technology is very distasteful to consumers and does not provide significant cost reductions to adopting producers ($\underline{\delta} > \overline{\sigma}$).

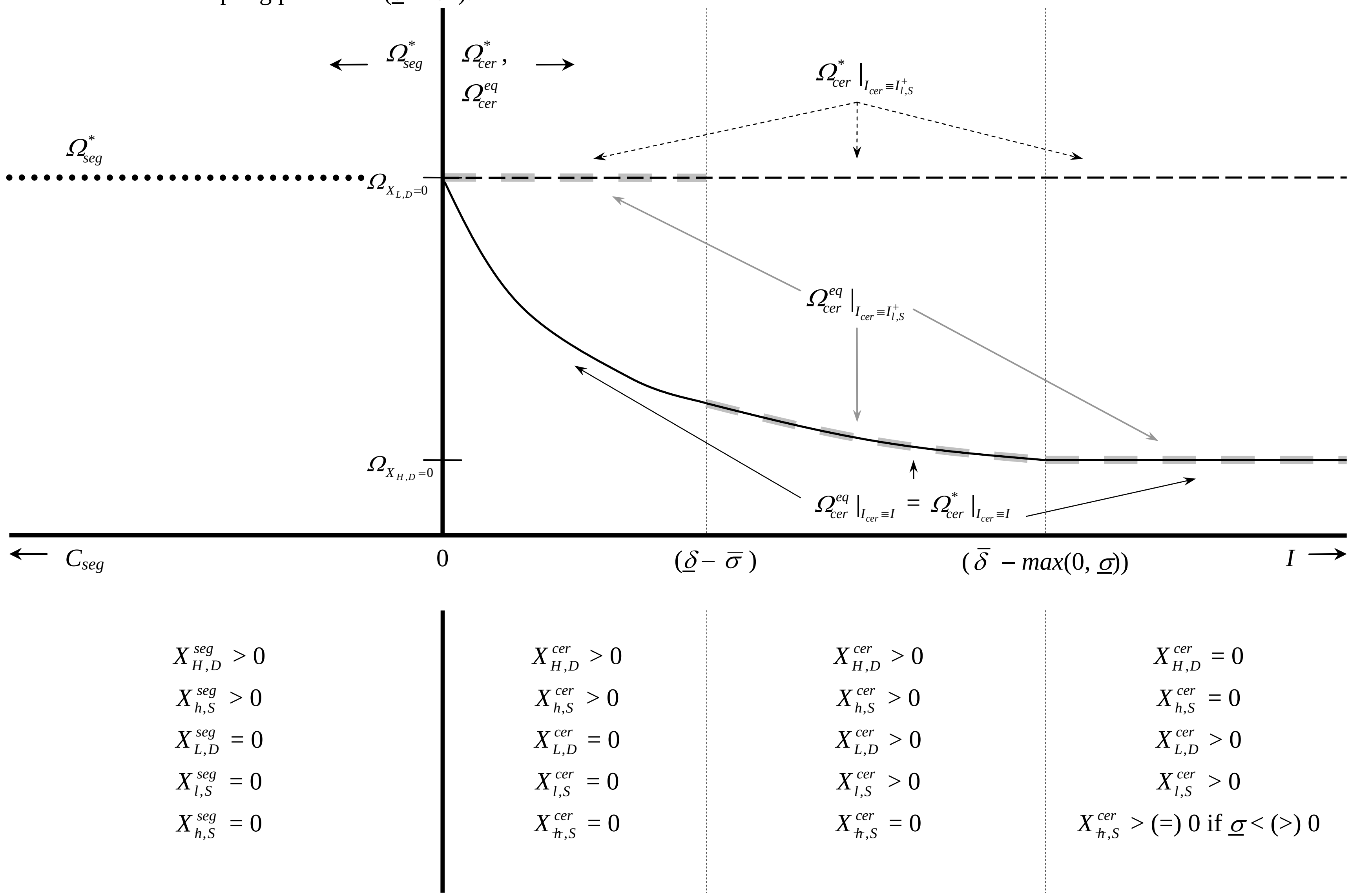


Figure 2. Social welfare functions when the undesirable technology is distasteful to a portion of consumers and reduces costs to all adopting producers ($\underline{\delta} < \overline{\sigma}$ and $\overline{\delta} > \underline{\sigma}$).

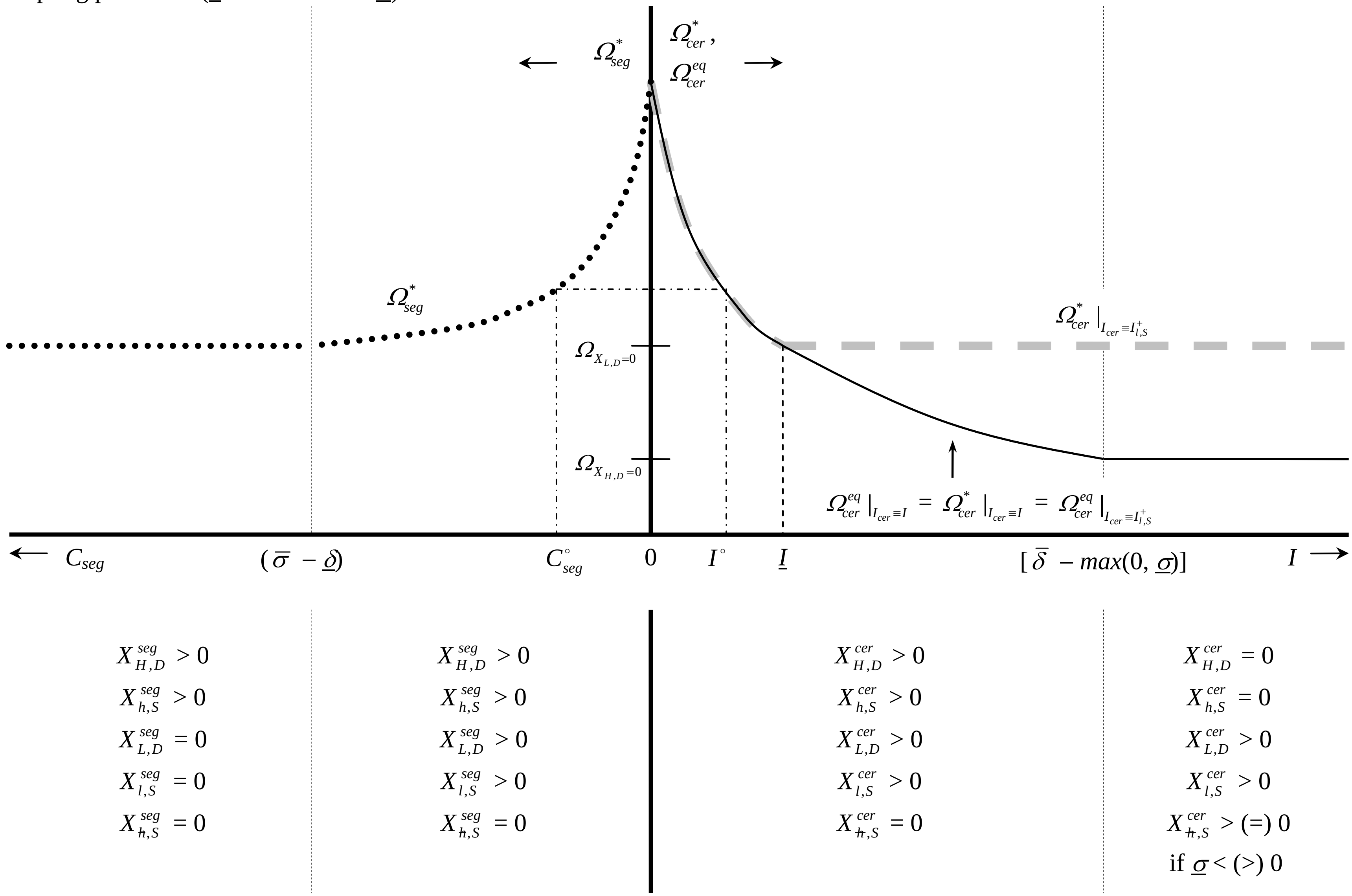
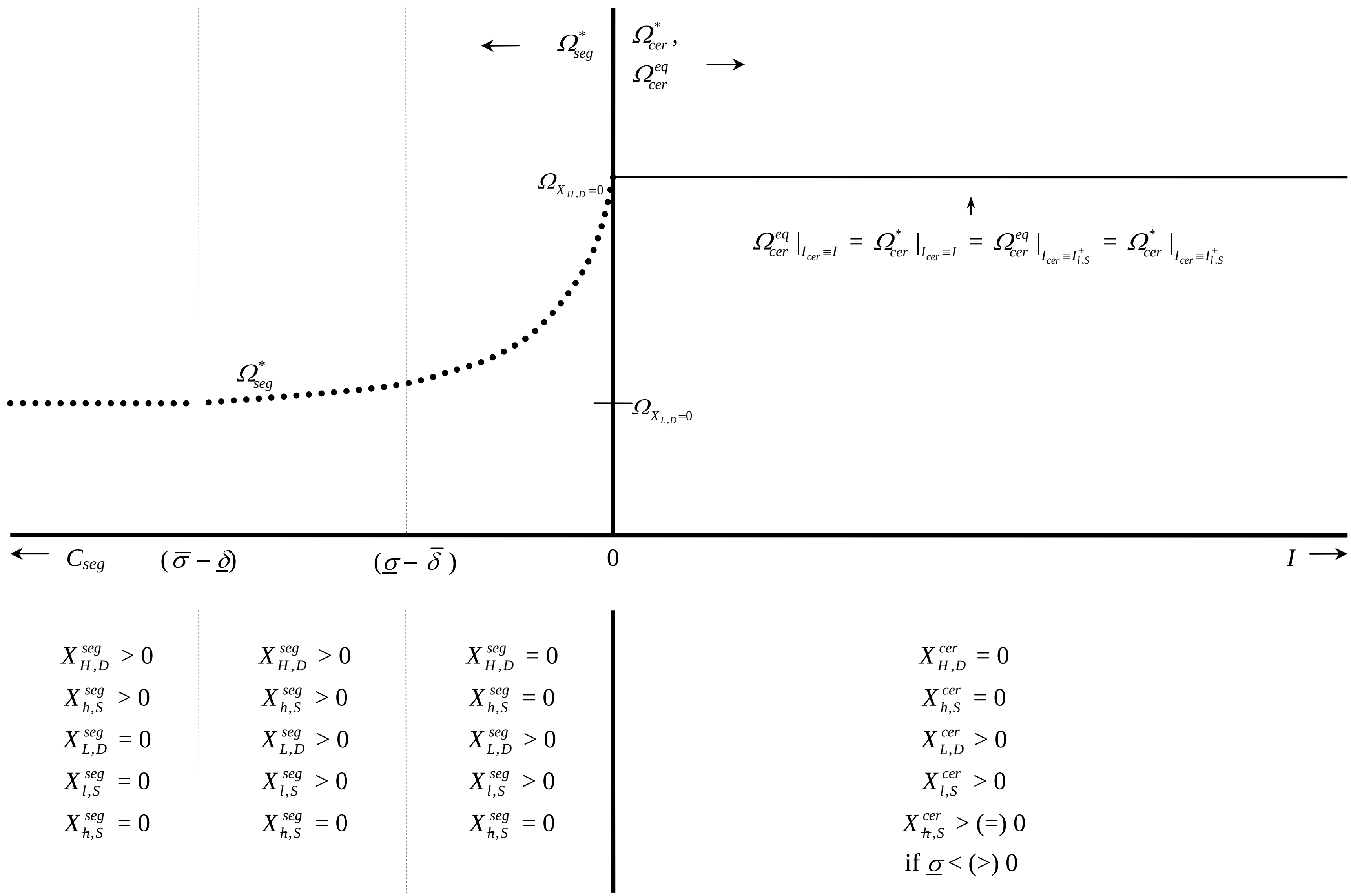


Figure 3. Social welfare functions when the undesirable technology is modestly distasteful for consumers and significantly reduces costs to all adopting producers ($\bar{\delta} < \underline{\sigma}$).



certification costs are high enough to render aggregate supply of high-quality good equal to zero (i.e., $I \geq \bar{\delta} - max(0, \underline{\sigma})$), however, further increases in certification costs do not affect the value function. This occurs because certification costs are associated only with supply of high-quality good.

Figure 2 illustrates two possible situations that may arise when the smallest premium consumers are willing to pay for the high-quality good is strictly smaller than the largest costs associated with the desirable technology ($\underline{\delta} < \bar{\sigma}$), but the minimum reward required by producers to use the latter is strictly smaller than the maximum premium consumers are willing to pay for the high-quality good ($\underline{\sigma} < \bar{\delta}$). Aggregate consumption of both the high- and low-quality goods is strictly positive if the certification cost parameter I is relatively small (i.e., $I < \bar{\delta} - max(0, \underline{\sigma})$). Otherwise, only low-quality good is supplied and consumed. Also, as in Figure 1, the value functions $\Omega^{eq}_{cer} = \Omega^{*}_{cer}$ are declining in the certification cost parameter I as long as aggregate supply of the high-quality good is strictly positive.

Finally, Figure 3 shows the case where the minimum costs from the desirable technology are greater than the maximum premium consumers are willing to pay for the high-quality good (i.e., $\underline{\sigma} > \bar{\delta}$). In this situation, aggregate output and consumption consist only of low-quality good regardless of certification costs, and the value functions $\Omega^{eq}_{cer} = \Omega^{*}_{cer}$ are independent of the certification cost parameter I.

Proposition 3 shows that the properties of the social welfare function, aggregate output and aggregate consumption under market equilibrium depend not only on the certification cost parameter I, but also on the supports of consumers' and producers' cdfs (i.e., $[\underline{\delta}, \bar{\delta}]$ and $[\underline{\sigma}, \bar{\sigma}]$, respectively). Appendix B shows that the welfare effects of infinitesimal changes in the distribution of consumer preferences ($F_D(\delta)$) and producer cost savings ($F_S(\sigma)$) holding their respective supports constant is ambiguous in general. However, Proposition 4 below summarizes special situations where such effects can be signed.

More precisely, consider a change of measure from cdf $F_D(\delta)$ to cdf $G_D(\delta; k_D)$:

(5.1) $$dG_D(\delta;\, k_D) \equiv \frac{[1+k_D h_D(\delta)]}{\int_{\underline{\delta}}^{\bar{\delta}} [1+k_D h_D(\delta)]\, dF_D(\delta)}\; dF_D(\delta),$$

where $k_D \geq 0$ is a constant and $h_D(\delta)$ is an arbitrary function satisfying the condition $[1 + k_D h_D(\delta)] > 0$.[3] Inspection of (5.1) reveals that judicious choices of function $h_D(\delta)$ allow $G_D(\delta;\, k_D)$ to represent *any* arbitrary cdf that assigns mass whenever $F_D(\delta)$ does. Note also that $F_D(\delta) = G_D(\delta; k_D)|_{k_D=0}$, hence $\Omega_{cer}^{eq}[F_D(\delta)] = \Omega_{cer}^{eq}[G_D(\delta; k_D)]|_{k_D=0}$. Define cdf $G_S(\sigma;\, k_S)$ based on cdf $F_S(\sigma)$ in an analogous manner. Given these definitions, Proposition 4 reports results regarding the effects of changing measures $F_D(\delta)$ and $F_S(\sigma)$ on societal welfare.

Proposition 4: Under the assumptions about consumers and producers stated in Sections 1 and 2, and the aforementioned assumptions about measures $G_D(\delta;\, k_D)$ and $G_S(\sigma;\, k_S)$, society's value function under market equilibrium exhibits the following properties:

a. $$\left.\frac{\partial \Omega_{cer}^{eq}[G_D(\delta; k_D)]}{\partial k_D}\right|_{k_D=0} = \begin{cases} 0 \text{ if } X_{L,D}^{eq} = 0, \\ < (>)\ 0 \text{ if } \partial h_D / \partial \delta > (<)\ 0 \text{ and } X_{L,D}^{eq} > 0, \end{cases}$$

b. $$\left.\frac{\partial \Omega_{cer}^{eq}[G_S(\sigma; k_S)]}{\partial k_S}\right|_{k_S=0} = \begin{cases} 0 \text{ if } X_{h,S}^{eq} = 0, \\ < (>)\ 0 \text{ if } \partial h_S / \partial \sigma > (<)\ 0 \text{ and } X_{h,S}^{eq} > 0. \end{cases}$$

Proof: See Appendix C.

Proposition 4 allows us to infer how changes in the distribution of consumers' taste and/or producers' technology (while holding the supports unchanged) will impact society's welfare under market equilibrium. Consider, for example, an infinitesimal change of measure with $\partial h_D/\partial\delta > 0$, which means that the new cdf is to the right of the original one (i.e., loosely speaking, consumers become slightly more averse to the undesirable technology). According to Proposition 4, such a change of measure will shift the welfare curve in Figures 1 through 3

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[3]In the language of measure theory, $F_D(\delta)$ and $G_D(\delta;\cdot)$ are *equivalent measures*, and the ratio on the left-hand side of (5.1) is the *Radon-Nikodym derivative* of $G_D(\delta;\cdot)$ with respect to $F_D(\delta)$ (e.g., Duffie, p. 324).

downward except when $I \in [0, \underline{\delta} - \overline{\sigma})$ in Figure 1, where the welfare curve will remain unchanged by the change of measure.

By a similar argument, it is straightforward to show that the societal welfare curve for $I < [\overline{\delta} - max(0, \underline{\sigma})]$ in Figures 1 and 2 decreases (increases) with a change of measure characterized by $\partial h_S/\partial\sigma > (<)\ 0$, which reflects larger (smaller) costs for the desirable technology. However, in Figure 3 and for $I > [\overline{\delta} - max(0, \underline{\sigma})]$ in Figures 1 and 2, the welfare curve will be unaffected regardless of the function $h_S(\sigma)$ involved in the change of measure.

6. Certification Costs Revisited

Up to this point, the analysis has proceeded under the assumption that certification costs must be incurred whenever one unit of output from the desirable technology is to be sold as high-quality good (i.e., $I_{cer} \equiv I$). However, such assumption need not be the most realistic. To see this, consider the scenario in Figure 1 with certification costs such that $0 \le I \le \underline{\delta} - \overline{\sigma}$. In this instance, all of the production is obtained by means of the desirable technology and therefore there is no need to certify.

Following the argument above, suppose now that the costs incurred in certification are defined as $I_{cer} \equiv I^{+}_{l,S}$, where $I^{+}_{l,S}$ equals I if aggregate output from the undesirable technology is strictly positive ($X_{l,S} > 0$), and zero otherwise. This alternative assumption about certification costs affects society's value function under market equilibrium only when $\underline{\delta} > \overline{\sigma}$, that is, the scenario depicted in Figure 1. The graph shows that $\Omega^{eq}_{cer}|_{I_{cer} \equiv I^{+}_{l,S}} = \Omega_{X_{L,D}=0} > \Omega^{eq}_{cer}|_{I_{cer} \equiv I}$ for $0 < I < \underline{\delta} - \overline{\sigma}$, because all of the production consists of the high quality good when certification cost parameter I is sufficiently small and the undesirable technology is very distasteful to consumers while yielding small cost savings to producers. If certification cost parameter I is sufficiently large, some low quality good is produced because some producers find it more profitable. Hence, $\Omega^{eq}_{cer}|_{I_{cer} \equiv I^{+}_{l,S}} = \Omega^{eq}_{cer}|_{I_{cer} \equiv I}$ for $I > \underline{\delta} - \overline{\sigma} > 0$.

Whether certification costs are defined as $I_{cer} \equiv I^{+}_{l,S}$ or $I_{cer} \equiv I$ matters for whether the market equilibrium outcome is isomorphic to the social planner's optimal solution. To see this, consider the market equilibrium welfare function depicted in Figure 2. In this scenario $I_{cer} \equiv I^{+}_{l,S} = I$ because there is a strictly positive aggregate output from the undesirable technology. Hence, the market equilibrium is the same as analyzed earlier in Section 5. Note, however, that for $I > \underline{I}$ a planner can achieve higher society welfare than a decentralized market by restricting all production to be obtained from the desirable technology only. For $I > \underline{I}$, the planner's value function $\Omega^{*}_{cer}|_{I_{cer}\equiv I^{+}_{l,S}}$ equals a constant $\Omega_{X_{L,D}=0}$ that is strictly greater than society's welfare under market equilibrium $\Omega^{eq}_{cer}|_{I_{cer}\equiv I_{l,S>0}}$, so the latter is not optimal. The planner's solution for $I > \underline{I}$ is not a market equilibrium because there is a positive mass of agents who strictly prefer to deviate from it. Producers who can save the most by switching to the undesirable technology are characterized by $\sigma = \overline{\sigma}$, and consumers with the least distaste for it have $\delta = \underline{\delta}$. Since $\overline{\sigma} > \underline{\delta}$ by assumption, both types of agents gain by switching to the undesirable technology.

Further, according to Figure 2, the loss in society welfare due to reliance on the market equilibrium rather than on the planner's solution increases with certification cost parameter I for $\underline{I} < I < \overline{\delta} - max(0, \underline{\sigma})$, and such a loss is greatest for $I \geq \overline{\delta} - max(0, \underline{\sigma})$. The same argument can be made for $I > \underline{\delta} - \overline{\sigma} > 0$ in Figure 1.

Figure 2 depicts the case $\Omega_{X_{L,D}=0} > \Omega_{X_{H,D}=0}$, where $\Omega_{X_{L,D}=0}$ and $\Omega_{X_{H,D}=0}$ denote the maximum social welfare that can be achieved when aggregate consumption consists only of high-quality good and low-quality good, respectively. That is, the cdfs $F_D(\delta)$ and $F_S(\sigma)$ underlying Figure 2 are such that, if society is restricted to consume only one type of good, it is better off producing and consuming the high-quality good than with the low-quality one. In the opposite scenario of $\Omega_{X_{L,D}=0} \leq \Omega_{X_{H,D}=0}$, it is straightforward to infer from Figure 2 that the market equilibrium is always the same as the social planner's optimal solution, regardless of the level of certification cost parameter I.

The findings from the preceding discussion are summarized below as Proposition 5:

Proposition 5: With certification costs given by $I_{cer} \equiv I^{+}_{l,S}$, a market equilibrium exists and is unique under the assumptions about consumers and producers stated in Sections 1 and 2.

However, the market equilibrium is not the same as the social planner's optimum if $\Omega_{X_{L,D}=0}$ > $\Omega_{X_{H,D}=0}$ and certification cost parameter I is sufficiently large.

Market Implementation of the Planner's Solution with Certification Costs $I_{cer} \equiv I^{+}_{l,S}$

The levels of certification cost parameter I for which the planner's solution strictly dominates the market equilibrium outcome are such that the planner only employs the desirable technology, so that $\Omega^{*}_{cer}|_{I_{cer} \equiv I^{+}_{l,S}} = \Omega_{X_{L,D}=0}$. Conceptually, this solution could be obtained as a market equilibrium outcome by banning the use of the undesirable technology. However, banning the undesirable technology would involve additional fraud-preventing costs $A_{ban} \geq 0$. This is true because the ban would require ensuring that producers only use the desirable technology. Clearly, other things equal, the larger A_{ban}, the larger the level of the certification cost parameter I required to justify banning the undesirable technology from the market. Further, the market equilibrium without a ban always dominates the market equilibrium with it if the ban is sufficiently expensive to implement (i.e., if $A_{ban} \geq \Omega_{X_{L,D}=0} - \Omega_{X_{H,D}=0}$).

7. Low-Quality Segregation Instead of High-Quality Certification

As an alternative to the assumption that the high-quality good is voluntarily certified (so as to permit verifiability of the claim that it is obtained by means of the desirable technology), it is instructive to consider the case where all output from the undesirable technology is mandated to be segregated and identified as such. If all of the undesirable technology output is segregated, all of the production from the desirable technology can be sold as high-quality good without need for costly certification. Therefore, this alternative assumption shifts costs from the suppliers of the high-quality good to the employers of the undesirable technology. Clearly, producers who use the undesirable technology will never segregate voluntarily, because doing so involves extra costs without enhancing the price received for their output. As a result, there are regulatory costs associated with mandatory segregation to prevent fraud. Segregation is best exemplified by the recent EU directive mandating segregation of food products obtained from GM organisms (Lence and Hayes 2005).

Leaving aside for the time being the potential costs associated with fraud prevention, the planner's problem when per-unit segregation costs are equal to $C_{seg} \geq 0$ can be expressed as:[4]

(7.1)
$$\max_{\{x_{H,\delta},x_{L,\delta},x_{h,\sigma},x_{\hbar,\sigma},x_{l,\sigma},\mu_H,\mu_L\}\forall\delta\in[\underline{\delta},\bar{\delta}]\text{ and }\sigma\in[\underline{\sigma},\bar{\sigma}]} \Omega_{seg} = W + \int_{\underline{\delta}}^{\bar{\delta}} [v(x_{H,\delta}+x_{L,\delta}) - \delta x_{L,\delta}]\, dF_D(\delta)$$
$$- \int_{\underline{\sigma}}^{\bar{\sigma}} [c(x_{h,\sigma}+x_{\hbar,\sigma}+x_{l,\sigma}) + \iota_{\sigma>0}\sigma(x_{h,\sigma}+x_{\hbar,\sigma}) + (C_{seg}-\iota_{\sigma\leq 0}\sigma)x_{l,\sigma}]\, dF_S(\sigma)$$
$$+ \mu_H \left[\int_{\underline{\sigma}}^{\bar{\sigma}} x_{h,\sigma}\, dF_S(\sigma) - \int_{\underline{\delta}}^{\bar{\delta}} x_{H,\delta}\, dF_D(\delta)\right]$$
$$+ \mu_L \left[\int_{\underline{\sigma}}^{\bar{\sigma}} x_{\hbar,\sigma}\, dF_S(\sigma) + \int_{\underline{\sigma}}^{\bar{\sigma}} x_{l,\sigma}\, dF_S(\sigma) - \int_{\underline{\delta}}^{\bar{\delta}} x_{L,\delta}\, dF_D(\delta)\right].$$

The FOCs for the above planner's optimum are obtained in a manner similar to the derivation of the FOCs corresponding to the optimization of (4.1), and are shown in Appendix D. Major properties of the planner's value function, aggregate production, and aggregate consumption under segregation are summarized in Proposition 6 below.

Proposition 6: Under segregation and the assumptions about consumers and producers stated in Sections 1 and 2, society's value function, optimal aggregate consumption, and optimal aggregate production exhibit the following properties regarding segregation cost parameter C_{seg}:

a. $\partial \Omega^*_{seg} / \partial C_{seg} = -X^{seg}_{l,S}$,
b. If $\bar{\sigma} - \underline{\delta} >$ (<) $C_{seg} > 0$: $\partial^2 \Omega^*_{seg} / \partial C^2_{seg} >$ (=) 0, $X^{seg}_{L,D} = X^{seg}_{l,S} >$ (=) 0.
c. If $\underline{\sigma} - \bar{\delta} >$ (<) $C_{seg} > 0$: $X^{seg}_{H,D} = X^{seg}_{h,S} =$ (>) 0
d. $X^{seg}_{\hbar,S} = 0$.

[4]Since segregation renders certification trivial, (7.1) is obtained by setting $I = 0$.

Proof: 6.a follows from application of the envelope theorem (e.g., Mas-Colell, Whinston, and Green, p. 964), which yields $\partial \Omega^*_{seg} / \partial C_{seg} = -\int_{\underline{\sigma}}^{\overline{\sigma}} x^{seg}_{l,\sigma}\, dF_S(\sigma) = -X^{seg}_{l,S}$. The proofs of 6.b, 6.c, and 6.d are shown in Appendix E. □

The main properties of the planner's value function under segregation (Ω^*_{seg}) regarding per-unit segregation costs C_{seg} are illustrated graphically on the left-hand orthants of Figures 1 through 3. The horizontal axis to the left of zero depicts C_{seg}, with values increasing as one moves further leftward. Variables below the left-hand side horizontal axes represent the corresponding planners' optimal aggregate consumption and production under the alternative technologies.

In Figures 1 through 3, the social planner's value function under segregation intersects the vertical axis at the same point as the social planner's value function under certification, i.e., $\Omega^*_{seg}|_{C_{seg}=0} = \Omega^*_{cer}|_{I=0}$. This is to be expected, as examination of (4.1) and (7.1) reveals that the planner's objective function under certification for $I = 0$ is identical to planner's objective function under segregation for $C_{seg} = 0$. In addition, for the scenario depicted in Figure 1, the planner's value function under segregation is constant and equal to $\Omega_{X_{L,D}=0}$, i.e., Ω^*_{seg} is independent of segregation costs when $\underline{\delta} > \overline{\sigma}$. This is also to be expected, because if the undesirable technology is so distasteful to consumers and yields so little cost savings that it is not used at all even if it costs nothing to segregate the low quality product ($\Omega^*_{seg}|_{C_{seg}=0} = \Omega^*_{cer}|_{I=0}$), the undesirable technology will obviously not be employed either if segregation costs are higher.

Allowing for segregation, for any given value of the certification cost parameter I and segregation cost C_{seg}, the planner's value function is the highest of the value functions under segregation and certification, i.e., $\Omega^* = max(\Omega^*_{cer}|_{I_{cer} \equiv I^+_{l,S}}, \Omega^*_{seg})$. In the scenario depicted in Figure 1, the outcome under segregation is the same as the social planner's optimum under certification. In contrast, in the other extreme scenario depicted by Figure 3, it is never optimal to segregate regardless of the level of C_{seg}. In the intermediate case depicted in Figure 2, whether segregation is optimal or not depends on the relative magnitudes of cost parameters C_{seg} and I. For example, the planner is indifferent between segregation and certification if $C_{seg} = C^{\circ}_{seg}$ and $I = I^{\circ}$, because

$\Omega^*_{seg}|_{C_{seg}=C^\circ_{seg}} = \Omega^*_{cer}|_{I=I^\circ}$. However, if C_{seg} < (>) C°_{seg} and $I = I^\circ$, then the planner's optimal choice is segregation (certification). Note also that in the scenario illustrated in Figure 2 but with $\Omega_{X_{H,D}=0} > \Omega_{X_{L,D}=0}$ (instead of $\Omega_{X_{H,D}=0} < \Omega_{X_{L,D}=0}$ as drawn), segregation is never optimal if segregation costs are sufficiently high.

Similar to the case of a ban on the undesirable technology, a conceptually possible market intervention consists of mandating segregation so as to achieve the planner's segregation solution as a market outcome, at the cost of incurring the associated regulatory expenses to prevent fraud. For the scenario depicted in Figure 1, which assumes zero regulatory costs, market equilibrium under mandatory segregation works like a ban in that it yields the social planner's optimum. Therefore, in such instance neither type of intervention strictly dominates the other, and either of them weakly dominates the non-intervention market outcome.

However, similar to implementing a ban, mandatory segregation in the presence of markets would entail additional fraud-preventing costs $A_{seg} \geq 0$ to prevent producers from employing the undesirable technology without segregating. Whether a ban is preferable to mandatory segregation or not depends crucially on their respective fraud-preventing costs, as society's welfare equals $\Omega_{X_{L,D}=0} - A_{ban}$ with a ban on the low-quality good, and (in Figures 2 and 3) is no smaller than $\Omega_{X_{L,D}=0} - A_{seg}$ with mandatory segregation. Clearly, market implementation of mandatory segregation strictly dominates that of a ban when fraud-preventing costs are smaller for the former (A_{seg}) than for the latter (A_{ban}). In the opposite situation where $A_{seg} > A_{ban}$, mandatory segregation is preferred to a ban if per-unit segregation costs (C_{seg}) are sufficiently small, but the opposite is true for sufficiently large per-unit segregation costs.

These results cast light on the literature on voluntary and mandatory labeling (Scatasta, Wesseler, and Hobbs). Producers of the undesirable technology will obviously not have any interest in voluntary labeling, yet there are times when societal welfare can be increased if this product is labeled. This label will only be used if it is mandatory.

Distributional Impacts of Banning and Segregation

As we have mentioned, the rationale for banning or segregating the undesirable product will depend heavily on the circumstances at hand. The circumstances under which banning makes most sense will typically exist when the benefits to producers of the undesirable technology is small relative to the distaste of consumers (i.e., the scenario depicted in Figure 1), certification costs are high, and the regulatory costs of preventing ban fraud are low. In this case, the primary beneficiaries of a ban will be those consumers who prefer the desirable technology and those producers who would have used the desirable technology even in the absence of a ban. Consumers and producers who would have participated in the market for the undesirable technology will lose.

Segregation makes most sense when the regulatory costs of preventing segregation fraud are low, a significant share though not a majority of consumers are relatively indifferent between the two technologies, and where benefits of the technology to producers are substantial (i.e., the scenario depicted in Figure 2). Under the unregulated market outcome, bulk handling facilities will always be used for the undesirable technology and the good produced with the desirable technology will move through niche channels. In some instances under the market outcome the volume of product moving through the niche system might eventually exceed the volume in the bulk handling system and in this case it is clear that segregation will improve societal welfare. Under segregation, the costs associated with the more expensive identity-preserved system are switched from the producers and consumers of the desirable technology to the producers and consumers of the undesirable technology. However, it may make sense for producers of the undesirable technology to support a segregated system. This would occur if the alternative to segregation is banning.

As of early 2009, there is a debate as to whether to allow the products of cloned animals in to the U.S. food system. If there is a substantial degree of consumer opposition to the introduction of these products, then the technology may be banned to avoid “contaminating” the general food supply with these products. In this instance, segregation may make most sense because it will allow producers of cloned animals to sell their output at a price that includes segregation costs given that the only politically valid alternative is to ban the technology.

9. Conclusions

Affluence has created interest in ethical aspects of production practices that have no measurable impact on the physical attributes of a product. Producers of these ethical goods have an incentive to certify their products via eco-labels and other similar certification programs. The costs associated with these certificates (and any identity preservation required to support these certificates) is borne by consumers of ethical products. Producers who use ethically inferior practices often encounter lower production costs and, since they have no incentive to segregate their products, they do not face identification costs when the market is unregulated. These lower costs are then passed on to consumers of the ethically inferior good. Under competitive market forces, this allocation of certification costs to consumers of the ethical product will occur regardless of the proportion of consumers who prefer the ethical product.

Government has at its disposal a set of regulatory tools that are not available to the free market, albeit at the cost of enforcing such regulations. It can ban the production of the ethically inferior good. Alternatively, it can require that the ethically inferior good be segregated, thereby shifting identity preservation costs to those who participate in the low-quality good market. Our contribution consists of exploring the circumstances under which the market equilibrium outcome is optimal from the standpoint of a social planner, and those under which it can be improved upon by means of different kinds of government intervention. It is shown that the optimal solution needs to be determined on a case-by-case basis and depends on the consumer preferences, the relative costs of the two production systems, the relative costs of segregation and certification, and the relative regulatory costs of preventing fraud under the alternative types of government intervention.

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Appendix A: Proof of Proposition 3

Proof of Proposition 3.b:

Proof that $X^{eq}_{H,D} = X^{eq}_{h,S}$ *= (>) 0 if* I *> (<)* $\bar{\delta}$ *– max(0,* $\underline{\sigma}$*):*

As noted in Section 2, an individual σ-type producer's output of certified good under the desirable technology is zero if $\sigma > \mu^{cer}_H - \mu^{cer}_L - I$ or $\mu^{cer}_H - \mu^{cer}_L - I < 0$, and strictly positive if $\sigma < \mu^{cer}_H - \mu^{cer}_L - I > 0$. Hence, $X^{eq}_{h,S}$ = (>) 0 if $\mu^{cer}_H - \mu^{cer}_L - I$ < (>) *max*(0, $\underline{\sigma}$). From Section 1, an individual δ-type consumer's demand for the high-quality good is zero (strictly positive) if δ < (>) $\mu^{cer}_H - \mu^{cer}_L$. Therefore, $X^{eq}_{H,D}$ = (>) 0 if $\bar{\delta}$ < (>) $\mu^{cer}_H - \mu^{cer}_L$. Since $X^{eq}_{h,S} = X^{eq}_{H,D}$ by Proposition 2, it must be the case that $X^{eq}_{h,S} = X^{eq}_{H,D}$ = (>) 0 if $\bar{\delta}$ < (>) $\mu^{cer}_H - \mu^{cer}_L$ < (>) *max*(0, $\underline{\sigma}$) + I or, equivalently, that $X^{eq}_{h,S} = X^{eq}_{H,D}$ = (>) 0 if I > (<) $\bar{\delta}$ – *max*(0, $\underline{\sigma}$). □

Proof that $\partial^2 \Omega^{eq}_{cer} / \partial I^2$ *= (>) 0 if* I *> (<)* $\bar{\delta}$ *– max(0,* $\underline{\sigma}$*):*

From the proof of Proposition 3.a, $\partial^2 \Omega^{eq}_{cer} / \partial I^2 = -\partial X^{eq}_{h,S} / \partial I$. Hence, $I > \bar{\delta}$ – *max*(0, $\underline{\sigma}$) ⇒ $\partial^2 \Omega^{eq}_{cer} / \partial I^2 = 0$ from the preceding proof. For $I < \bar{\delta}$ – *max*(0, $\underline{\sigma}$), expression $-\partial X^{eq}_{h,S} / \partial I$ can be signed by using Proposition 2 to reduce the planner's FOCs to the aggregate conditions (4.7) and (4.8). There are two possible cases, namely, (1) $X^{eq}_{L,D} = X^{eq}_{\hbar,S} + X^{eq}_{l,S} = 0$ and (2) $X^{eq}_{L,D} = X^{eq}_{\hbar,S} + X^{eq}_{l,S} > 0$.

Case 1: If $X^{eq}_{L,D} = X^{eq}_{\hbar,S} + X^{eq}_{l,S} = 0$, we have

(A.1) $$\partial^2 \Omega^*_{cer} / \partial I^2 = \partial[-\int_{\underline{\sigma}}^{\bar{\sigma}} c'^{-1}(\mu^{cer}_H - I - \iota_{\sigma>0}\,\sigma)\, dF_S(\sigma)]/\partial I^2,$$

(A.1') $$= -\varphi_S \frac{\partial \mu^{cer}_H}{\partial I} + \varphi_S,$$

(A.1'') $$= \varphi_S\, \varphi_D / (\varphi_S + \varphi_D) > 0,$$

where $\varphi_S \equiv \int_{\underline{\sigma}}^{\bar{\sigma}} \{c''[c'^{-1}(\mu^{cer}_H - I - \iota_{\sigma>0}\,\sigma)]\}^{-1} dF_S(\sigma) > 0$ and $\varphi_D \equiv -\int_{\underline{\delta}}^{\bar{\delta}} \{v''[v'^{-1}(\mu^{cer}_H)]\}^{-1} dF_D(\delta) > 0$. Derivative $\partial \mu^{cer}_H / \partial I = \varphi_S/(\varphi_S + \varphi_D) > 0$ is obtained by rearranging the expression resulting from totally differentiating (A.2) (which is the expression for (4.7) corresponding to this scenario):

(A.2) $\int_{\underline{\sigma}}^{\overline{\sigma}} c'^{-1}(\mu_H^{cer} - I - \iota_{\sigma>0}\,\sigma)\, dF_S(\sigma) - \int_{\underline{\delta}}^{\overline{\delta}} v'^{-1}(\mu_H^{cer})\, dF_D(\delta) = 0.$

Case 2: If $X_{L,D}^{eq} = X_{h,S}^{eq} + X_{l,S}^{eq} > 0$, we have

(A.3) $\partial^2 \Omega_{cer}^{eq}/\partial I^2 = \partial[-\int_{\underline{\sigma}}^{\mu_H^{cer}-\mu_L^{cer}-I} c'^{-1}(\mu_H^{cer} - I - \iota_{\sigma>0}\,\sigma)\, dF_S(\sigma)\,]/\partial I^2,$

(A.3') $\quad = -(\varphi_{S1} + \varphi_{S2})\dfrac{\partial \mu_H^{cer}}{\partial I} + \varphi_{S2}\dfrac{\partial \mu_L^{cer}}{\partial I} + \varphi_{S1} + \varphi_{S2},$

(A.3") $\quad = \{(\varphi_{D1} + \varphi_{D2})\,[\varphi_{S1}\,(\varphi_{S2} + \varphi_{S3}) + \varphi_{S2}\,\varphi_{S3}]$

$\quad + (\varphi_{S1} + \varphi_{S2})\,[\varphi_{D1}\,(\varphi_{D2} + \varphi_{D3}) + \varphi_{D2}\,\varphi_{D3}]\}/\Phi > 0,$

where $\Phi \equiv [(\varphi_{S1} + \varphi_{D1})\,(\varphi_{S3} + \varphi_{D3}) + (\varphi_{S2} + \varphi_{D2})\,(\varphi_{S1} + \varphi_{D1} + \varphi_{S3} + \varphi_{D3})] > 0$, $\varphi_{S1} \equiv \int_{\underline{\sigma}}^{\mu_H^{cer}-\mu_L^{cer}-I} \{c''[c'^{-1}(\mu_H^{cer} - I - \iota_{\sigma>0}\,\sigma)]\}^{-1}\, dF_S(\sigma) > 0$, $\varphi_{S2} \equiv c'^{-1}(\mu_L^{cer})\; f_S(\mu_H^{cer} - \mu_L^{cer} - I) > 0$, $\varphi_{S3} \equiv \int_{\mu_H^{cer}-\mu_L^{cer}-I}^{\overline{\sigma}} \{c''[c'^{-1}(\mu_L^{cer})]\}^{-1}\, dF_S(\sigma) > 0$, $\varphi_{D1} \equiv -\int_{\mu_H^{cer}-\mu_L^{cer}}^{\overline{\delta}} \{v''[v'^{-1}(\mu_H^{cer})]\}^{-1}\, dF_D(\delta) > 0$, $\varphi_{D2} \equiv v'^{-1}(\mu_H^{cer})\; f_D(\mu_H^{cer} - \mu_L^{cer}) > 0$, $\varphi_{D3} \equiv -\int_{\underline{\delta}}^{\mu_H^{cer}-\mu_L^{cer}} \{v''[v'^{-1}(\mu_L^{cer} + \delta)]\}^{-1}\, dF_D(\delta) > 0$, $f_S(\sigma) \equiv dF_S(\sigma)/d\sigma \geq 0$, and $f_D(\delta) \equiv dF_D(\delta)/d\delta \geq 0$. Derivatives $\partial \mu_H^{cer}/\partial I = [(\varphi_{S1} + \varphi_{S2})\,(\varphi_{S3} + \varphi_{D3}) + \varphi_{S1}\,(\varphi_{S2} + \varphi_{D2})]/\Phi > 0$ and $\partial \mu_L^{cer}/\partial I = (\varphi_{S1}\,\varphi_{D2} - \varphi_{S2}\,\varphi_{D1})/\Phi$ are obtained by rearranging the expressions resulting from total differentiation of (A.4) and (A.5) (which are the expressions corresponding to (4.7) and (4.8), respectively, for this particular scenario):

(A.4) $\int_{\underline{\sigma}}^{\mu_H^{cer}-\mu_L^{cer}-I} c'^{-1}(\mu_H^{cer} - I - \iota_{\sigma>0}\,\sigma)\, dF_S(\sigma) - \int_{\mu_H^{cer}-\mu_L^{cer}}^{\overline{\delta}} v'^{-1}(\mu_H^{cer})\, dF_D(\delta) = 0,$

(A.5) $\int_{\mu_H^{cer}-\mu_L^{cer}-I}^{\overline{\sigma}} c'^{-1}(\mu_L^{cer})\, dF_S(\sigma) - \int_{\underline{\delta}}^{\mu_H^{cer}-\mu_L^{cer}} v'^{-1}(\mu_L^{cer} + \delta)\, dF_D(\delta) = 0.$ □

Proof of Proposition 3.c:

From the explanation following (2.2) through (2.4), no firm with $\sigma > 0$ will produce good employing the desirable technology without certification, i.e., $X_{h,S}^{eq} = 0$ if $\underline{\sigma} > 0$. Further, no firm with $\sigma < 0$ will produce good employing the desirable technology without certification if $X_{h,S}^{eq} > 0$. Hence, by Proposition 3.b, $X_{h,S}^{eq} = 0$ if $\underline{\sigma} < 0$ but $I < \overline{\delta} - max(0, \underline{\sigma})$ (= $\overline{\delta}$ if $\underline{\sigma} < 0$).

Also from the explanation following (2.2) through (2.4), firms with $\sigma < 0$ will produce uncertified good only if $X_{h,S}^{eq} = 0$. By Proposition 3.b, $X_{h,S}^{eq} > 0$ if $\underline{\sigma} < 0$ and $I > \bar{\delta} - max(0, \underline{\sigma})$ (= $\bar{\delta}$ if $\underline{\sigma} < 0$). □

Proof of Proposition 3.d:

Note that:

i. $X_{l,S}^{eq} = (>) \ 0$ if $\bar{\sigma} < (>) \ \mu_H^{cer} - \mu_L^{cer} - I$, because an individual σ-type producer's supply of good from the undesirable technology is strictly positive if $0 < \sigma > \mu_H^{cer} - \mu_L^{cer} - I$, and zero if $\sigma < 0$ or $\sigma < \mu_H^{cer} - \mu_L^{cer} - I$ (see Section 2).

ii. An individual δ-type consumer's demand for the low-quality good is zero (strictly positive) if $\delta > (<) \ \mu_H^{cer} - \mu_L^{cer}$, which implies that $X_{L,D}^{eq} = (>) \ 0$ if $\underline{\delta} > (<) \ \mu_H^{cer} - \mu_L^{cer}$ (see Section 1).

From (i) and (ii), $X_{L,D}^{eq} = X_{l,S}^{eq} = 0$ if $\underline{\delta} > \mu_H^{cer} - \mu_L^{cer} > I + \bar{\sigma}$, and $X_{L,D}^{eq} > 0$ and $X_{l,S}^{eq} > 0$ if $\underline{\delta} < \mu_H^{cer} - \mu_L^{cer} < I + \bar{\sigma}$. □

Appendix B: Welfare Effects of Infinitesimal Changes in Consumer and Producer Cdfs

Proposition B.1: Under the assumptions about consumers and producers stated in Sections 1 and 2, respectively, and the assumptions about measures $G_D(\delta; k_D)$ and $G_S(\sigma; k_S)$ made in the discussion regarding (5.1), society's value function under market equilibrium exhibits the following properties:

a. $$\left.\frac{\partial \Omega_{cer}^{eq}[G_D(\delta;k_D)]}{\partial k_D}\right|_{k_D=0} = Cov_{F_D}[V^{eq},\ h_D(\delta)],$$

b. $$\left.\frac{\partial \Omega_{cer}^{eq}[G_S(\sigma;k_S)]}{\partial k_S}\right|_{k_S=0} = Cov_{F_S}[\Pi^{eq},\ h_S(\sigma)],$$

where $Cov_F(P, h)$ represents the covariance between P and h under measure F, V^{eq} is the indirect utility function (1.4) evaluated at market equilibrium, and Π^{eq} is the profit function (2.5) also evaluated at market equilibrium.

Proof: Upon simplification, substitution of FOCs (4.2)-(4.8) into (4.1) yields (B.1):

$$\text{(B.1)}\quad \Omega^*_{cer}[G_D(\delta;k_D),G_S(\sigma;k_S)]|_{k_D=k_S=0} = \int_{\underline{\delta}}^{\bar{\delta}} V(\mu^{cer}_\delta)\; dG_D(\delta;k_D)|_{k_D=0} + \int_{\underline{\sigma}}^{\bar{\sigma}} \Pi(\mu^{cer}_\sigma)\; dG_S(\sigma;k_S)|_{k_S=0},$$

where $\mu^{cer}_\delta \equiv min(\mu^{cer}_H,\ \mu^{cer}_L + \delta)$ and $\mu^{cer}_\sigma \equiv max(\mu^{cer}_H - I - \iota_{\sigma>0}\ \sigma,\ \mu^{cer}_L)$. Therefore:

$$\text{(B.2)}\quad \left.\frac{\partial\Omega^*_{cer}[G_D(\delta;k_D),G_S(\sigma;k_S)]}{\partial k_D}\right|_{k_D=k_S=0} = \int_{\underline{\delta}}^{\bar{\delta}} V(\mu^{cer}_\delta)\; h_D(\delta)\; dG_D(\delta;k_D)|_{k_D=0} - \left[\int_{\underline{\delta}}^{\bar{\delta}} V(\mu^{cer}_\delta)\; dG_D(\delta;k_D)|_{k_D=0}\right]\left[\int_{\underline{\delta}}^{\bar{\delta}} h_D(\delta)\, dG_D(\delta;k_D)|_{k_D=0}\right],$$

$$\text{(B.2')}\quad = \int_{\underline{\delta}}^{\bar{\delta}} V(\mu^{cer}_\delta)\; h_D(\delta)\; dF_D(\delta) - \left[\int_{\underline{\delta}}^{\bar{\delta}} V(\mu^{cer}_\delta)\; dF_D(\delta)\right]\left[\int_{\underline{\delta}}^{\bar{\delta}} h_D(\delta)\, dF_D(\delta)\right],$$

$$\text{(B.3)}\quad \left.\frac{\partial\Omega^*_{cer}[G_D(\delta;k_D),G_S(\sigma;k_S)]}{\partial k_S}\right|_{k_D=k_S=0} = \int_{\underline{\sigma}}^{\bar{\sigma}} \Pi(\mu^{cer}_\sigma)\; h_S(\sigma)\; dG_S(\sigma;k_S)|_{k_S=0} - \left[\int_{\underline{\sigma}}^{\bar{\sigma}} \Pi(\mu^{cer}_\sigma)\; dG_S(\sigma;k_S)|_{k_S=0}\right]\left[\int_{\underline{\sigma}}^{\bar{\sigma}} h_S(\delta)\, dG_S(\sigma;k_S)|_{k_S=0}\right],$$

$$\text{(B.3')}\quad = \int_{\underline{\sigma}}^{\bar{\sigma}} \Pi(\mu^{cer}_\sigma)\; h_S(\sigma)\; dF_S(\sigma) - \left[\int_{\underline{\sigma}}^{\bar{\sigma}} \Pi(\mu^{cer}_\sigma)\; dF_S(\sigma)\right]\left[\int_{\underline{\sigma}}^{\bar{\sigma}} h_S(\delta)\, dF_S(\sigma)\right],$$

Propositions B.1.a and B.1.b follow immediately from (B.2') and (B.3'), respectively, because $Cov_F(P, h) = E_F(P\ h) - E_F(P)\ E_F(h)$ for any random variables P and h, where $E_F(\cdot)$ denotes the expectation operator under measure F. □

Appendix C: Proof of Proposition 4

Proof of Proposition 4.a:

From the discussion of (1.4), $\partial V/\partial P_\delta = -v'^{-1}(P_\delta) < 0$ is the negative of a δ-type consumer's demand. Therefore, V is independent of δ if $\delta > P^{eq}_H - P^{eq}_L$, strictly decreasing in δ if $\delta < P^{eq}_H$ −

P_L^{eq}, and non-increasing in δ if $\delta = P_H^{eq} - P_L^{eq}$.[1] It follows that $X_{L,D}^{eq} = 0 \Rightarrow \underline{\delta} \geq P_H^{eq} - P_L^{eq} \Rightarrow$ $Cov_{F_D}[V,\ h_D(\delta)] = 0$. If $X_{L,D}^{eq} > 0$, V is non-increasing in δ in general, and strictly decreasing over some interval in $[\underline{\delta},\ \overline{\delta}\ ]$. Since $h_D(\delta)$ is strictly increasing (decreasing) if $\partial h_D(\delta)/\partial\delta > (<)\ 0$, the condition that $X_{L,D}^{eq} > 0$ and $\partial h_D(\delta)/\partial\delta > (<)\ 0$ implies that V and $h_D(\delta)$ exhibit strictly negative (positive) covariation over a range of δ with strictly positive mass. The desired result then follows immediately from Proposition B.1.a in Appendix B. □

Proof of Proposition 4.b:

From the discussion of (2.5), $\partial\Pi/\partial P_\sigma = c'^{-1}(P_\sigma) > 0$ is a σ-type firm supply. Hence, Π is independent of σ if $\sigma > P_H^{eq} - P_L^{eq} - I$ or $P_H^{eq} - P_L^{eq} - I < 0$, strictly decreasing in σ if $\sigma < P_H^{eq} - P_L^{eq} - I > 0$, and non-increasing in σ if $\sigma = P_H^{eq} - P_L^{eq} - I$.[2] Thus, $X_{h,S}^{eq} = 0 \Rightarrow max(0,\ \underline{\sigma}) \geq P_H^{eq} - P_L^{eq} - I \Rightarrow Cov_{F_S}[\Pi,\ h_S(\sigma)] = 0$. If $X_{h,S}^{eq} > 0$, Π is non-increasing in general, and strictly decreasing over some interval in $[\underline{\sigma},\ \overline{\sigma}\ ]$. Since $h_S(\sigma)$ is strictly increasing (decreasing) if $\partial h_S(\sigma)/\partial\sigma > (<)\ 0$, the condition that $X_{h,S}^{eq} > 0$ and $\partial h_S(\sigma)/\partial\sigma > (<)\ 0$ implies that Π and $h_S(\sigma)$ exhibit strictly negative (positive) covariation over a range of σ with strictly positive mass. The desired result then follows immediately from Proposition B.1.b in Appendix B. □

Appendix D: FOCs Corresponding to Optimization of (7.1)

FOCs for each consumer of type $\delta \in [\underline{\delta}, \overline{\delta}]$ are (D.1) and (D.2), FOCs for each producer of type $\sigma \in [\underline{\sigma}, \overline{\sigma}]$ are (D.3) through (D.5), and the FOCs corresponding to the lagrangian multipliers are (D.6) and (D.7):

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[1]The derivative $\partial P_\delta^{eq}/\partial\delta$ does not exist if $\delta = P_H^{eq} - P_L^{eq}$, but in such instance the left-hand and right-hand derivatives of P_δ^{eq} with respect to δ are one and zero, respectively. Note also that differentiability of $F_D(\delta)$ implies zero mass for consumers of type δ.

[2]The derivative $\partial P_\sigma^{eq}/\partial\sigma$ does not exist if $\sigma = P_H^{eq} - P_L^{eq} - I$, but in such instance the left-hand and right-hand derivatives of P_σ^{eq} with respect to σ are minus one and zero, respectively. Note also that differentiability of $F_S(\sigma)$ implies zero mass for producers of type σ.

$$\text{(D.1)} \quad \frac{\partial \Omega^*_{seg}}{\partial x_{H,\delta}} = -\ \mu_H^{seg} + v'(x_{H,\delta}^{seg} + x_{L,\delta}^{seg}) \leq 0,\ x_{H,\delta}^{seg} \geq 0,\ x_{H,\delta}^{seg}\ \frac{\partial \Omega^*_{seg}}{\partial x_{H,\delta}} = 0,$$

$$\text{(D.2)} \quad \frac{\partial \Omega^*_{seg}}{\partial x_{L,\delta}} = -\,(\,\mu_L^{seg} + \delta) + v'(x_{H,\delta}^{seg} + x_{L,\delta}^{seg}) \leq 0,\ x_{L,\delta}^{seg} \geq 0,\ x_{L,\delta}^{seg}\ \frac{\partial \Omega^*_{seg}}{\partial x_{L,\delta}} = 0,$$

$$\text{(D.3)} \quad \frac{\partial \Omega^*_{seg}}{\partial x_{h,\sigma}} = \mu_H^{seg} - c'(x_{h,\sigma}^{seg} + x_{\hbar,\sigma}^{seg} + x_{l,\sigma}^{seg}) - \iota_{\sigma>0}\ \sigma \leq 0,\ x_{h,\sigma}^{seg} \geq 0,\ x_{h,\sigma}^{seg}\ \frac{\partial \Omega^*_{seg}}{\partial x_{h,\sigma}} = 0,$$

$$\text{(D.4)} \quad \frac{\partial \Omega^*_{seg}}{\partial x_{\hbar,\sigma}} = \mu_L^{seg} - c'(x_{h,\sigma}^{seg} + x_{\hbar,\sigma}^{seg} + x_{l,\sigma}^{seg}) - \iota_{\sigma>0}\ \sigma \leq 0,\ x_{\hbar,\sigma}^{seg} \geq 0,\ x_{\hbar,\sigma}^{seg}\ \frac{\partial \Omega^*_{seg}}{\partial x_{\hbar,\sigma}} = 0,$$

$$\text{(D.5)} \quad \frac{\partial \Omega^*_{seg}}{\partial x_{l,\sigma}} = \mu_L^{seg} - c'(x_{h,\sigma}^{seg} + x_{\hbar,\sigma}^{seg} + x_{l,\sigma}^{seg}) - C_{seg} + \iota_{\sigma\leq 0}\ \sigma \leq 0,\ x_{l,\sigma}^{seg} \geq 0,\ x_{l,\sigma}^{seg}\ \frac{\partial \Omega^*_{seg}}{\partial x_{l,\sigma}} = 0,$$

$$\text{(D.6)} \quad \frac{\partial \Omega^*_{seg}}{\partial \mu_H} = \int_{\underline{\sigma}}^{\bar{\sigma}} x_{h,\sigma}^{seg}\ dF_S(\sigma) - \int_{\underline{\delta}}^{\bar{\delta}} x_{H,\delta}^{seg}\ dF_D(\delta) \geq 0,\ \mu_H^{seg} \geq 0,\ \mu_H^{seg}\ \frac{\partial \Omega^*_{seg}}{\partial \mu_H} = 0,$$

$$\text{(D.7)} \quad \frac{\partial \Omega^*_{seg}}{\partial \mu_L} = \int_{\underline{\sigma}}^{\bar{\sigma}} x_{\hbar,\sigma}\ dF_S(\sigma) + \int_{\underline{\sigma}}^{\bar{\sigma}} x_{l,\sigma}\ dF_S(\sigma) - \int_{\underline{\delta}}^{\bar{\delta}} x_{L,\delta}\ dF_D(\delta) \geq 0,\ \mu_L^{seg} \geq 0,\ \mu_L^{seg}\ \frac{\partial \Omega^*_{seg}}{\partial \mu_L} = 0.$$

Appendix E: Proof of Proposition 6

Proof of Proposition 6.d:

From FOCs (D.1) through (D.7), at the optimum aggregate consumption and production can be expressed as (E.1) and (E.2), and (E.3) through (E.5), respectively:

$$\text{(E.1)} \quad X_{H,D}^{seg} = \int_{\mu_H^{seg} - \mu_L^{seg}}^{\bar{\delta}} v'^{-1}(\mu_H^{seg})\, dF_D(\delta),$$

$$\text{(E.2)} \quad X_{L,D}^{seg} = \int_{\underline{\delta}}^{\mu_H^{seg} - \mu_L^{seg}} v'^{-1}(\mu_L^{seg} + \delta)\, dF_D(\delta).$$

$$\text{(E.3)} \quad X_{h,S}^{seg} = \begin{cases} \displaystyle\int_{\underline{\sigma}}^{\mu_H^{seg} - \mu_L^{seg} + C_{seg}} c'^{-1}(\mu_H^{seg} - \iota_{\sigma\rangle 0}\sigma)\, dF_S(\sigma) & \text{if } \mu_H^{seg} - \mu_L^{seg} \geq 0, \\ 0 \text{ otherwise.} & \end{cases}$$

$$\text{(E.4)} \quad X_{h,S}^{seg} = \begin{cases} \int_{\underline{\sigma}}^{C_{seg}} c'^{-1}(\mu_L^{seg} - \iota_{\sigma \rangle 0}\sigma)\, dF_S(\sigma) & \text{if } \mu_H^{seg} - \mu_L^{seg} \leq 0, \\ 0 \text{ otherwise.} \end{cases}$$

$$\text{(E.5)} \quad X_{l,S}^{seg} = \int_{max(0,\mu_H^{seg}-\mu_L^{seg})+C_{seg}}^{\overline{\sigma}} c'^{-1}(\mu_L^{seg} - C_{seg} + \iota_{\sigma \leq 0}\sigma)\, dF_S(\sigma)$$

Further, a proof analogous to the proof of Proposition 2 can be employed to demonstrate that there is no excess aggregate production over consumption at the optimum (i.e., $X_{H,D}^{seg} = X_{h,S}^{seg}$ and $X_{L,D}^{seg} = X_{h,S}^{seg} + X_{l,S}^{seg}$). But if $\mu_H^{seg} \leq \mu_L^{seg}$, according to (E.1) and (E.2) aggregate consumption will consist only of high-quality good (i.e., $X_{L,D}^{seg} = 0$),[3] whereas (E.4) and (E.5) indicate that aggregate supply of the low-quality good will be greater than zero ($X_{h,S}^{seg} + X_{l,S}^{seg} > 0$), which violates the condition $X_{L,D}^{seg} = X_{h,S}^{seg} + X_{l,S}^{seg}$. Hence, $\mu_H^{seg} > \mu_L^{seg}$, which implies that $X_{h,S}^{seg} = 0$. □

Proof of Proposition 6.c:

From the proof of 6.d above, at the optimum $X_{H,D}^{seg} = X_{h,S}^{seg}$, $X_{L,D}^{seg} = X_{l,S}^{seg}$, and $\mu_H^{seg} > \mu_L^{seg}$. Further, $x_{H,\delta}^{seg} = (>)\ 0$ if $\mu_H^{seg} - \mu_L^{seg} > (<)\ \delta$ from FOCs (D.1) and (D.2), and $x_{h,\sigma}^{seg} = (>)\ 0$ if $\mu_H^{seg} - \mu_L^{seg} + C_{seg} < (>)\ \sigma$ from FOCs (D.3) and (D.5). Hence, $X_{H,D}^{seg} = (>)\ 0$ if $\mu_H^{seg} - \mu_L^{seg} > (<)\ \overline{\delta}$, and $X_{h,S}^{seg} = (>)\ 0$ if $\mu_H^{seg} - \mu_L^{seg} + C_{seg} < (>)\ \underline{\sigma}$. It then follows that $X_{H,D}^{seg} = X_{h,S}^{seg} = 0$ if $\overline{\delta} < \mu_H^{seg} - \mu_L^{seg} < \underline{\sigma} - C_{seg}$, and $X_{H,D}^{seg} = X_{h,S}^{seg} > 0$ if $\overline{\delta} > \mu_H^{seg} - \mu_L^{seg} > \underline{\sigma} - C_{seg}$. □

Proof of Proposition 6.b:

Proof that $X_{L,D}^{seg} = X_{l,S}^{seg} > (=)\ 0$ *if* $\overline{\sigma} - \underline{\delta} > (<)\ C_{seg} > 0$:

From the proof of Proposition 6.d above, at the optimum $X_{H,D}^{seg} = X_{h,S}^{seg}$, $X_{L,D}^{seg} = X_{l,S}^{seg}$, and $\mu_H^{seg} > \mu_L^{seg}$. In addition, FOCs (D.1) and (D.2) imply that $x_{L,\delta}^{seg} > (=)\ 0$ if $\mu_H^{seg} - \mu_L^{seg} > (<)\ \delta$, and FOCs (D.3) and (D.5) yield $x_{l,\sigma}^{seg} > (=)\ 0$ if $\mu_H^{seg} - \mu_L^{seg} + C_{seg} < (>)\ \sigma$. It follows that $X_{L,D}^{seg} > (=)\ 0$ if $\mu_H^{seg} - \mu_L^{seg} > (<)\ \underline{\delta}$, and $X_{l,S}^{seg} > (=)\ 0$ if $\mu_H^{seg} - \mu_L^{seg} + C_{seg} < (>)\ \overline{\sigma}$. Hence, $X_{L,D}^{seg} = X_{l,S}^{seg} > 0$ if $\underline{\delta} < \mu_H^{seg} - \mu_L^{seg} < \overline{\sigma} - C_{seg}$, and $X_{L,D}^{seg} = X_{l,S}^{seg} = 0$ if $\underline{\delta} > \mu_H^{seg} - \mu_L^{seg} > \overline{\sigma} - C_{seg}$. □

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[3]Recall that $\underline{\delta} \geq 0$, and that the assumption that $F_S(\sigma)$ is differentiable implies the mass of consumers with a particular δ is zero.

Proof that $\partial^2\Omega^*_{seg}/\partial C^2_{seg}$ *> (=) 0 if* $\bar{\sigma} - \underline{\delta}$ *> (<)* C_{seg} *> 0:*

Note that $\partial^2\Omega^*_{seg}/\partial C^2_{seg} = -\partial X^{seg}_{l,S}/\partial C_{seg}$ by Proposition 6.a. Hence, it must be the case that $\partial^2\Omega^*_{seg}/\partial C^2_{seg} = 0$ if $C_{seg} > \bar{\sigma} - \underline{\delta}$, because the preceding proof shows that $X^{seg}_{l,S} = 0$ if $\underline{\delta} > \bar{\sigma} - C_{seg}$. For $C_{seg} > \bar{\sigma} - \underline{\delta}$, expression $-\partial X^{seg}_{l,S}/\partial C_{seg}$ can be signed by using the fact that $X^{seg}_{l,S} = X^{seg}_{L,D} > 0$ and either (1) $X^{seg}_{H,D} = X^{seg}_{h,S} = 0$, or (2) $X^{seg}_{H,D} = X^{seg}_{h,S} > 0$ (see proof of Proposition 6.d). It is proven next that $\partial X^{seg}_{l,S}/\partial C_{seg}$ < in both cases, so $\partial^2\Omega^*_{seg}/\partial C^2_{seg} > 0$ if $C_{seg} > \bar{\sigma} - \underline{\delta}$.

Case 1: If $X^{seg}_{L,D} = X^{seg}_{l,S} > 0$ and $X^{seg}_{H,D} = X^{seg}_{h,S} = 0$, one can obtain $\partial\mu^{seg}_L/\partial C_{seg} = \xi_S/(\xi_S + \xi_D) > 0$, where $\xi_S \equiv \int_{\underline{\sigma}}^{\bar{\sigma}} \{c''[c'^{-1}(\mu^{seg}_L - C_{seg} + \iota_{\sigma\le 0}\,\sigma)]\}^{-1}\, dF_S(\sigma) > 0$ and $\xi_D \equiv -\int_{\underline{\delta}}^{\bar{\delta}} \{v''[v'^{-1}(\mu^{seg}_L + \delta)]\}^{-1}\, dF_D(\delta) > 0$, by rearranging the expression resulting from totally differentiating (E.6):

(E.6) $$\partial\Omega^*_{seg}/\partial\mu_L = \int_{\underline{\sigma}}^{\bar{\sigma}} c'^{-1}(\mu^{seg}_L - C_{seg} + \iota_{\sigma\le 0}\sigma)\, dF_S(\sigma) - \int_{\underline{\delta}}^{\bar{\delta}} v'^{-1}(\mu^{seg}_L + \delta)\, dF_D(\delta) = 0.$$

Therefore:

(E.7) $$\partial^2\Omega^*_{seg}/\partial C^2_{seg} = \partial[-\int_{\underline{\sigma}}^{\bar{\sigma}} c'^{-1}(\mu^{seg}_L - C_{seg} + \iota_{\sigma\le 0}\,\sigma)\, dF_S(\sigma)]/\partial C^2_{seg},$$

(E.7') $$= -\,\xi_S\,\partial\mu^{seg}_L/\partial C_{seg} + \xi_S,$$

(E.7'') $$= \xi_S\,\xi_D/(\xi_S + \xi_D) > 0.$$

Case 2: If $X^{seg}_{L,D} = X^{seg}_{l,S} > 0$ and $X^{seg}_{H,D} = X^{seg}_{h,S} > 0$, we have

(E.8) $$\frac{\partial\Omega^*_{seg}}{\partial\mu_H} = \int_{\underline{\sigma}}^{\mu^{seg}_H - \mu^{seg}_L + C_{seg}} c'^{-1}(\mu^{seg}_H - \iota_{\sigma\rangle 0}\sigma)\, dF_S(\sigma) - \int_{\mu^{seg}_H - \mu^{seg}_L}^{\bar{\delta}} v'^{-1}(\mu^{seg}_H)\, dF_D(\delta) = 0,$$

(E.9) $$\frac{\partial\Omega^*_{seg}}{\partial\mu_L} = \int_{\mu^{seg}_H - \mu^{seg}_L + C_{seg}}^{\bar{\sigma}} c'^{-1}(\mu^{seg}_L - C_{seg} + \iota_{\sigma\le 0}\sigma)\, dF_S(\sigma) - \int_{\underline{\delta}}^{\mu^{seg}_H - \mu^{seg}_L} v'^{-1}(\mu^{seg}_L + \delta)\, dF_D(\delta) = 0.$$

Total differentiation of (E.8) and (E.9) yields $\partial\mu^{seg}_H/\partial C_{seg} = (\xi_{D2}\,\xi_{S3} - \xi_{S2}\,\xi_{D3})/\Theta$ and $\partial\mu^{seg}_L/\partial C_{seg} = [(\xi_{S2} + \xi_{S3})(\xi_{S1} + \xi_{D1}) + \xi_{S3}(\xi_{S2} + \xi_{D2})]/\Theta > 0$, where $\Theta \equiv [(\xi_{S1} + \xi_{D1})(\xi_{S3} + \xi_{D3})$

$+ (\xi_{S2} + \xi_{D2})\,(\xi_{S1} + \xi_{D1} + \xi_{S3} + \xi_{D3})] > 0$, $\xi_{S1} \equiv \int_{\underline{\sigma}}^{\mu_H^{seg} - \mu_L^{seg} + C_{seg}} \{c''[c'^{-1}(\mu_H^{seg} - \iota_{\sigma>0}\,\sigma)]\}^{-1}\, dF_S(\sigma) > 0$, $\xi_{S2} \equiv c'^{-1}[min(\mu_H^{seg}, \mu_L^{seg} - C_{seg})]\; f_S(\mu_H^{seg} - \mu_L^{seg} + C_{seg}) > 0$, $\xi_{S3} \equiv \int_{\mu_H^{seg} - \mu_L^{seg} + C_{seg}}^{\bar{\sigma}} \{c''[c'^{-1}(\mu_L^{seg} - C_{seg} + \iota_{\sigma\le 0}\sigma)]\}^{-1}\, dF_S(\sigma) > 0$, $\xi_{D1} \equiv -\int_{\mu_H^{seg} - \mu_L^{seg}}^{\bar{\delta}} \{v''[v'^{-1}(\mu_H^{seg})]\}^{-1}\, dF_D(\delta) > 0$, $\xi_{D2} \equiv v'^{-1}(\mu_H^{seg})\; f_D(\mu_H^{seg} - \mu_L^{seg}) > 0$, and $\xi_{D3} \equiv -\int_{\underline{\delta}}^{\mu_H^{seg} - \mu_L^{seg}} \{v''[v'^{-1}(\mu_L^{seg} + \delta)]\}^{-1}\, dF_D(\delta) > 0$.

Then:

(E.10) $\partial^2 \Omega_{seg}^* / \partial C_{seg}^2 = \partial[-\int_{\mu_H^{seg} - \mu_L^{seg} + C_{seg}}^{\bar{\sigma}} c'^{-1}(\mu_L^{seg} - C_{seg} + \iota_{\sigma\le 0}\sigma) dF_S(\sigma)] / \partial C_{seg}$,

(E.10') $= \xi_{S2}\;\, \mu_H^{seg} / \partial C_{seg} - (\xi_{S2} + \xi_{S3})\;\, \mu_L^{seg} / \partial C_{seg} + \xi_{S2} + \xi_{S3}$,

(E.10'') $= \{(\xi_{D2} + \xi_{D3})\,[\xi_{S1}\,(\xi_{S2} + \xi_{S3}) + \xi_{S2}\;\xi_{S2}]$

$+ (\xi_{S2} + \xi_{S3})\,[\xi_{D1}\,(\xi_{D2} + \xi_{D3}) + \xi_{D2}\;\xi_{D3}]\}/\Theta > 0.$ □