Quality Signaling and International Trade in Food Products

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Abstract

Focusing on the issue of food safety, we consider a framework of repeated purchases under the scenario of imperfect information on product quality (adverse selection and experience goods). A firm in a northern country can more easily detect tainted products than can a southern one. When imports are banned, the northern firm does not always signal the actual quality of its products. Competition from imports may lead the northern firm to test the quality of its products as a way to differentiate itself from foreign competitors. Consumers benefit from the disclosure of information on quality, even though borders are open to products of uncertain quality. However, competition from imports also increases the cost of signaling high quality. This can be detrimental to the welfare of the importing country when the cost of detection is high.

Key words: adverse selection, north-south trade, signaling, trade.

QUALITY SIGNALING AND INTERNATIONAL TRADE IN FOOD PRODUCTS

Introduction

Trade liberalization has put on the shelves an increasingly large number of products from more distant and more varied locations. The arrival of less familiar goods has sometimes resulted in concerns about the "globalization" of the economy. Consumers often maintain that they are not as well informed about the quality of imports as they are about the quality of domestic products. The issue is particularly sensitive in the food sector. For example, several American organizations have expressed concern about the safety of food imported from developing countries and have lobbied against international agreements that would help facilitate access to U.S. markets for imports, such as the special provisions of the Sanitary and Phytosanitary Agreement for developing countries (Silverglade 1998). On the other hand, developing and transition countries frequently voice their displeasure at sanitary standards requiring specific detection techniques, some of which are out of their reach (Henson et al. 2000).[1] These countries claim that recent requirements for quality certification present a de facto ban on access to European Union (EU) and U.S. markets for their products. The consequences go far beyond the food sector. During the Uruguay Round, developing countries saw access to northern markets in the food sector as the main motivation for participating in multilateral agreements, where they felt they otherwise had a lot to lose (e.g., on intellectual property). Because they feel that, in spite of lower tariffs, their access to the northern market did not improve because of technical requirements on quality control, they see little interest in participating in a new round of multilateral negotiations.

Granting access to northern markets without fueling consumers' worries is a key issue for a future trade agreement. The aim of this paper is to assess possible effects of trade liberalization when producers and consumers are imperfectly informed about food safety. We focus on a case where a country that is able to implement sophisticated sanitary control procedures (referred to as the "northern" country) opens its domestic market to goods produced in a “southern” country, where efficient means for detecting the actual quality of exports are lacking. The term “southern” is used for clarity of exposition and has no particular geographical meaning. Indeed, in order to focus on the information-related mechanisms, we do not assume that southern products are less safe on average; we assume only that detection of tainted products is more difficult for the southern country.

Our main results are the following. First, under autarky, the northern firm does not always detect the safety of its products. Consequently, low-quality (i.e., hazardous) products are sometimes sold, and the market equilibrium is thus characterized by an informational inefficiency. Second, opening the northern market to imports from the southern country may increase domestic welfare, even if the southern producer is unable to detect its product quality. Potential competition may increase the incentive for the northern producer to acquire and disclose more information. However, competition from the southern firm makes it costlier for the northern firm to signal high quality. For large probabilities of contamination and a large cost of detection, trade liberalization may result in market closure and have an overall negative effect on domestic welfare.

We focus on a case of quality detection by producers that are initially uninformed about the quality of their products and where there is an asymmetry in the acquisition of information between two countries. This differs from the literature on international trade under asymmetric information, where sellers most often are aware of their product quality. Grossman and Shapiro (1988) and Falvey (1989) focus on reputation effects when producers choose their quality (i.e., moral hazard). Donnenfeld (1986) and Donnenfeld, Weber, and Ben-Zion (1985) deal with the issue of consumers who are more informed about the quality of domestic products than about the quality of foreign ones. Haucap, Wey, and Barmbold (2000) investigate the role of imperfect information as an explanation for intra-industry trade. We investigate the interrelations between competition and acquisition/revelation of information. In our case, the firms’ information is endogenous—producers chose to detect quality or not—and their decision is influenced by trade. Our framework differs from Daughety and Reinganum (1997), who also focus on the signaling strategies of two competing firms with uninformed buyers but assume that quality levels are correlated across firms.

The Model

We begin with a simple, stylized framework. In the northern country, there are n identical consumers, and a single firm represents producers. There is a single firm and no consumers in the southern country. Production, trade, and consumption take place over two periods. A common discount factor $d<1$ is used for valuing the second-period gains relative to the first-period ones. Agents are risk neutral. For both firms, the marginal cost of production, c (identical in both countries) is constant, regardless of the quality of the product. There are only two product qualities. We assume that quality depends on a random contamination of the product beyond the firms' control. We also assume that the quality of output from a given firm remains unchanged in the second period. This corresponds to a case where contamination affects the plant or other structural production or marketing conditions, and we assume that a contaminated plant results in a low-quality product with a probability equal to one. Each firm offers either a high-quality product with probability l, or a low-quality product with probability $(1-l)$. This probability is the same in both countries.[2] The n consumers purchase either zero or one unit of the good in each period. Their willingness to pay for a safe product is $q_h>0$. The willingness to pay for tainted products is zero, so that there is no demand when the individual consumer is aware of the low quality of the product. We assume that $q_h>c$, meaning high-quality products are always purchased when the consumer is informed of the quality.

"North" and "south" only differ in the ability of firms to implement quality tests and therefore to get private information about contamination of the plant and the subsequent product quality.[3] In the northern country, we assume that the firm has the ability to ascertain perfectly whether the plant is safe or not at the beginning of period 1, provided that it incurs a (sunk) cost k in testing. The southern country cannot detect quality because of the lack of technology and human capital and is therefore unaware of the actual quality of its output in the first period. In the first period, consumers are not aware of the quality of the product available in the market by their own observation. Consumers do not observe whether or not the northern firm conducted a quality test and therefore do not observe the result of the test.[4] But as l, k, and c are assumed to be common knowledge, consumers can anticipate the conditions under which the firm has an incentive to get this private information by testing and to signal it through an introductory price. They can therefore identify a credible signal that the firm is of high quality and can use the information in their purchasing decision.

The timing of events is as follows:

1. In the first period, the northern firm decides whether or not to detect its quality. We assume that the test provides this information before the output is produced. If a firm does not produce after detecting its quality, it experiences no marginal cost of production, so that the only cost incurred in the absence of production is k.
2. Consumers observe prices and decide whether or not to purchase. At the end of the first period, each consumer is aware of the quality of the product consumed (i.e., quality is known after consumption, a case of experience goods). Through word of mouth, the quality of the goods consumed in the first period becomes common knowledge. In the second period, all agents are informed of the quality of the first-period suppliers, and consumers choose high-quality products.

These assumptions might seem restrictive; however, they make it possible to focus on the linkage between trade and quality revelation. By considering identical costs and probability of contamination, we ignore comparative advantage effects other than the informational one. By assuming an inelastic demand, we ignore the effect of extra competition resulting from trade liberalization on the Harberger triangles (i.e., deadweight loss) caused by market power. By considering only the northern market, we ignore the effect of economies of scale due to the fixed cost and the larger market under bilateral opening. By considering that only safe products are in demand, we ignore the welfare effect of a potential increase in product diversity caused by trade.

Autarky

When imports are banned, the northern firm is the only possible supplier in both periods. Before posting any price, the firm chooses among (*i*) production without quality detection, (*ii*) production with quality detection, and (*iii*) no production. By observing production, consumers cannot immediately distinguish between a firm that has not conducted a test, a firm that detected low quality, and a firm that detected high quality.

The first-period price may, however, convey information to consumers. This price is determined as a perfect Bayesian equilibrium of the subgame that starts after the decision regarding detection. In the second period, the firm sets a price $p_2=q_h$ if it turns out that its products, experienced by consumers, are of high quality, and no price otherwise. Next, we describe strategies (*i*), (*ii*), and (*iii*).

Strategy (i). If the nondetection strategy is chosen, the firm expects a profit $n[p\text{-}c+l\,d(q_h\text{-}c)]$ by posting a first-period price p. This profit is maximum with a price equal to the n consumer's willingness to pay in the first period, i.e., $p=l\,q_h$. The maximum expected profit with this strategy is Π_C given by equation (1). The consumer's expected surplus is zero, so that the domestic welfare W_C , defined as the sum of the consumer's and domestic firm's surplus, is Π_C.

$$W_C=\Pi_C=n\left(l\,q_h-c+l\,d(q_h-c)\right). \tag{1}$$

Strategy (ii). Detection involves a cost k but allows a firm to signal high quality. We represent this signal by a low introductory price. This common assumption encompasses various signaling strategies that involve a first-period investment in reputation (Shapiro 1983). The firm that chooses the detection strategy has no incentive to post the first-period price $l\,q_h$ that conveys no additional information. Such a strategy would be strictly dominated by strategy (*i*) where the firm does not incur the cost k (i.e., $\Pi_C - k<\Pi_C$). The signaling price must convince consumers both that quality detection was undertaken and that the firm offers high-quality goods. Because there is no demand for low-quality goods, a price lower than marginal cost is the only way to signal high-quality products.[5] Each individual consumer interprets the low price as the firm's commitment to be present on the market in the second period. As a result, consumers modify their expectation about the product's quality. An equilibrium is said to be separating if the high-quality seller posts a price p_S that it could not select if it was of low quality or if it did not detect its quality. Here, the highest possible signaling price is

$$\mathrm{p_S} = \mathrm{c}\text{-}\,l\,d\,(\mathrm{q_h} - c) - e\ , \tag{2}$$

with e close to 0. Neither an informed low-quality firm nor an uninformed one can expect positive profits by posting p_S. A firm informed of its low quality does not post a price lower than marginal cost in the first period (as it expects no sales in the second period when consumers are informed). A firm that has not detected its quality expects second-period profits with a probability l and can consider a first-period loss. However, the lowest possible first-period price for an uninformed firm is $p=c - l d(q_h - c)$, such that its expected profit $\pi=n(p - c+l d(q_h - c))$ is zero. Therefore, the price p_S is a credible signal for a firm with a high-quality output. Rational expectations allow consumers to anticipate when the firm has an *ex ante* incentive to detect and signal its quality, so that any price higher than p_S would then be understood as a low-quality signal. A firm with low-quality products (or with no information) thus does not post any price.

The intertemporal profit of the high-quality firm that detects and signals quality is $p_h=n[(p_S - c)+d(q_h - c)] - k$. If the firm is of low quality, a possibility occurring with a probability of $(1-l)$, its profit is $p_L= -k$. Before choosing to detect its quality, the domestic firm therefore knows that its overall average expected profit is Π_B.

$$\Pi_B = l p_h + (1-l) p_L = l n\left(-e + (1-l) d (q_h - c)\right) - k \,. \tag{3}$$

When the firm detects its quality, consumers experience a positive surplus in the first period, because the signaling price is lower than their willingness to pay q_h, and they experience no surplus in the second period. The intertemporal consumer surplus is $SC_B=n l\ (q_h - p_S)$. The sum of SC_B and the expected profit Π_B given by equation (3) gives the domestic welfare W_B for the separating equilibrium

$$W_B = n l (1+d)(q_h - c) - k \,. \tag{4}$$

Strategy (*iii*). Finally, if the firm does not produce, its profit and the consumer's surplus are zero.

The firm selects the most profitable strategy between (*i*), (*ii*), and (*iii*). We can characterize the behavior of the northern firm under autarky by Proposition 1, illustrated by Figure 1. The X-axis represents the probability l of supplying high-quality products

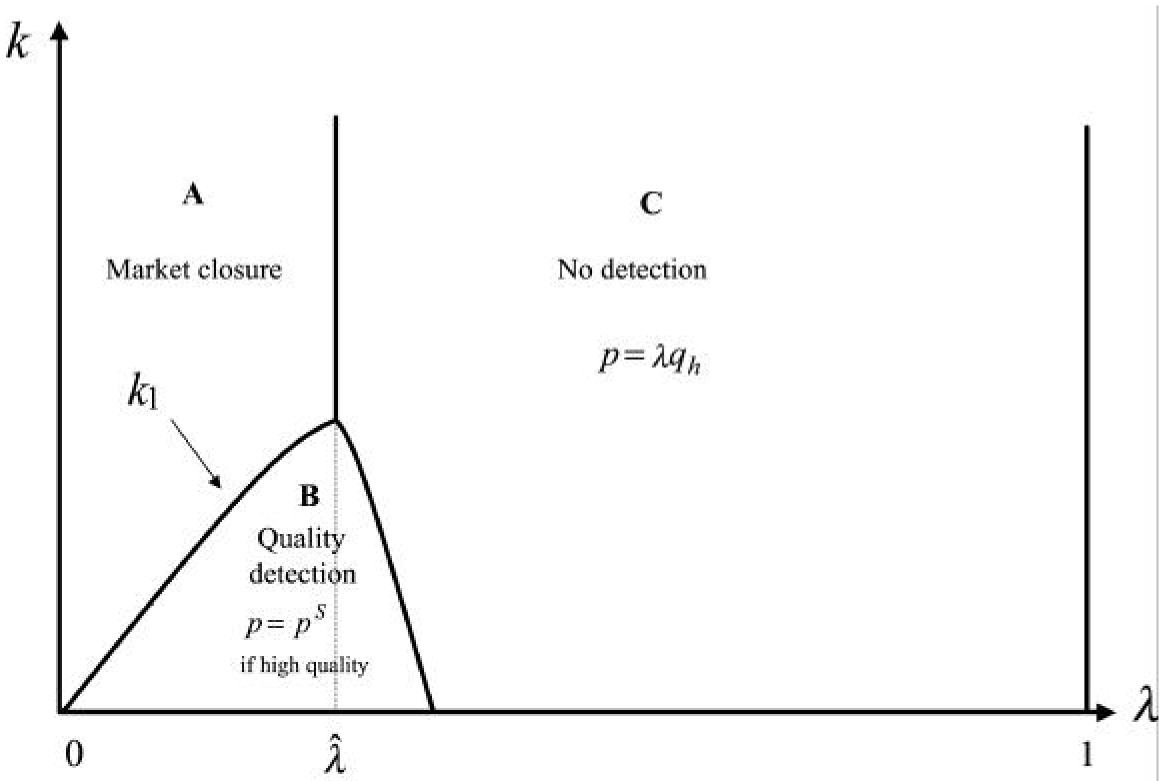

FIGURE 1. Quality detection and first-period pricing strategies under autarky

and the Y-axis represents the cost of quality testing *k*. The relative values of l and *k* determine the firm's optimal strategy.

PROPOSITION 1. *Under autarky, in area A of Figure 1, there is no production. In area B, the domestic firm chooses to detect its quality and, if it is of high quality, posts a first-period price* p_S. *In area C, the domestic firm does not detect its quality and posts a first-period price of* $l q_h$. *(See the proof in Appendix A).*

In area *A*, imperfect information results in a market closure. The low probability l implies a low willingness to pay for such an uncertain quality, and the relatively high cost of detection *k* deters the firm from acquiring information, so that the firm cannot expect a positive intertemporal profit. In area *B*, the firm chooses to detect quality in order to avoid a market closure (or a low profit in the absence of detection). In area *C*, the probability of getting high-quality products l is high and the firm has no incentive to implement a costly quality detection procedure given the high value of the consumer's willingness to pay $l q_h$ for a product of uncertain quality. In brief, under autarky, the functioning of the market may result in the absence of quality revelation in the first period and/or in a market closure. For relatively low values of k in area C, the welfare W_C given by equation (1) is lower than the welfare with quality detection W_B given by equation (4). It means that the firm does not detect its quality, even though it would be socially preferable to do so.

Trade Liberalization

In this section, the northern (hereafter “domestic”) country opens its domestic market to the southern (hereafter “foreign”) firm. We begin with the different pricing strategies in the two situations (detection/nondetection) before considering the choice of quality detection.

Pricing Strategies When the Domestic Firm Does Not Detect Product Quality

First, assume that the domestic firm does not detect product quality. Firms in both countries therefore have the same information regarding their quality and they compete in price over two periods. The repeated purchase framework and the exit of low-quality producers at the end of the first period allow sophisticated pricing strategies, even though the two firms have the same initial characteristics in costs, expected quality, and available information.

If both firms select the same price in period 1, consumers visit any seller and each firm sells a quantity $n/2$. The second-period price depends on the quality observed by consumers in period 1. With a probability $(1-l)^2$, both firms offered low quality in period 1 and there is no trade in period 2. With a probability l^2, both firms offered high quality in period 1 and competition results in a price equal to c in period 2. With a probability $l(1-l)$, only one firm offered high-quality products in period 1 and posts a price q_h, capturing all consumers in period 2. Thus, for each firm posting a price p in period 1, the expected profit is p^D:

$$p^{D}(p_i = p_j = p) = (n/2)(p - c) + nd\,l(1 - l)(q_h - c)\ . \qquad (5)$$

The lowest first-period price that firms are willing to set is such that their intertemporal profit is zero, which leads to a price $\overline{p}$:

$$\overline{p} = c - 2dl(1-l)(q_h - c)\,. \qquad (6)$$

Now, consider what happens when firms post different prices in period 1. Assume that firm *i* posts a price p_i and firm *j* posts a price $p_j = p_i + e$, with $e > 0$. Firm *i* captures all consumers in period 1. If consumers determine that *i* is of high quality, they will choose between firm *i* products and firm *j* products of unknown quality in period 2. This limits the price that the seller *i* can set in period 2 to p_2:[6]

$$p_2 = Min\left(q_h, c + (1-l)q_h\right). \qquad (7)$$

The expected profit of firm *i* is therefore p_I:

$$p_i\,(p_i\,, p_j > p_i) = n\left(p_i - c + dl\,(p_2 - c)\right) = n\left(p_i - c + dl\,(1-l)q_h\right) if\ l > c/q_h\,. \qquad (8)$$

By posting a price $p_i + e$, firm *j* makes no sale in period 1 but sells its product in period 2 if consumers find that firm *i* is of low quality. As nobody experienced its product in period 1, the firm *j* posts a price $l q_h$ and gets a profit p_j, given by equation (9):

$$p_j = n\ d(1-l)(lq_h - c)\,. \qquad (9)$$

We now turn to the choice between possible pricing strategies. Let $\tilde{p}$ be the price for which the profit resulting from selling in the first period is equal to the profit resulting from betting only on second-period sales (i.e., $p_i(p_i, p_j > p_i) = p_j$):

$$\tilde{p} = c - d(1-l)c\,. \qquad (10)$$

Figure 2 (above the curve k_2) illustrates Proposition 2 and shows the firm's decision in the absence of detection.[6]

PROPOSITION 2. *In area A, Figure 2, there is a market closure. In area C1, both firms post a first-period price* $\overline{p}$ *. In area C2, both firms post a first-period price* $\tilde{p}$ *. In area C3, one firm posts a price* $\tilde{p}$ *and the other posts a price* $\tilde{p} + e$ *in the first period. (See the proof and the technical explanations for Figure 2 in Appendix B).*

In areas *A* and *C*1, firms cannot expect positive profits in the second period unless they sold in the first period. In area *A*, no price can offset the low probability of getting

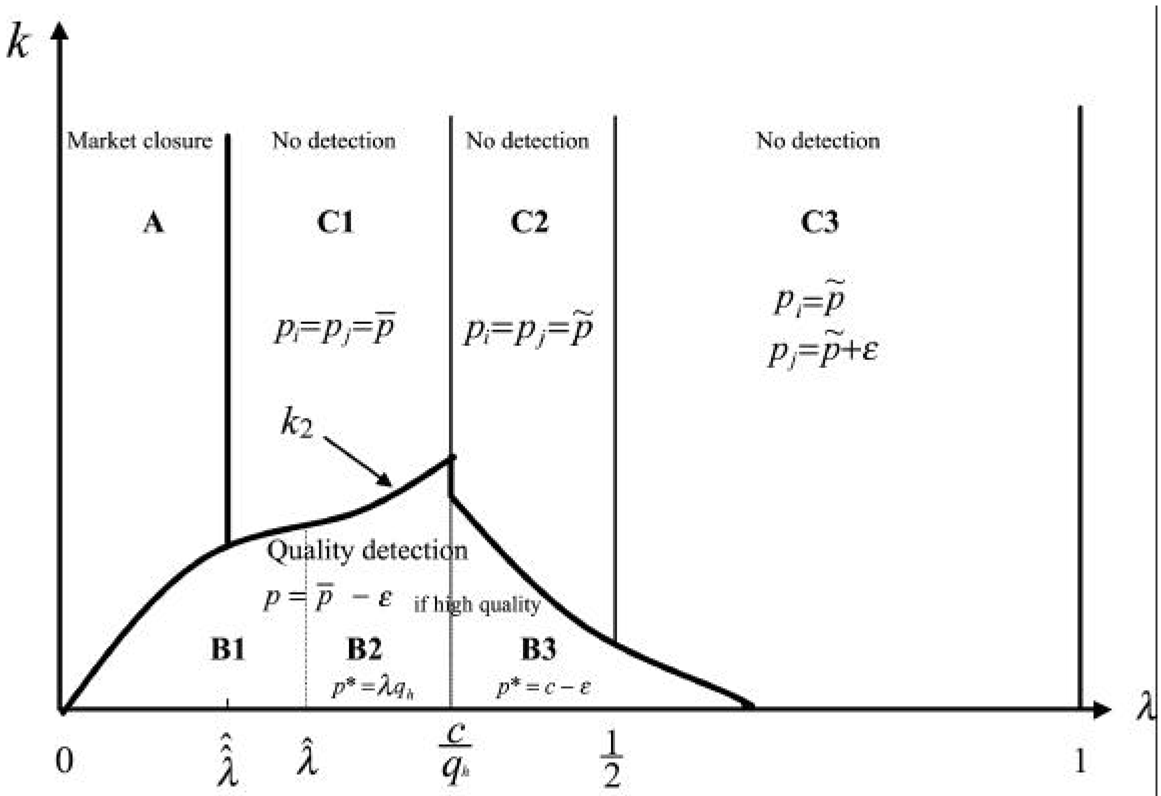

FIGURE 2. Quality detection and first-period pricing strategies under free trade

high quality, which deters consumers from purchasing. In area *C*1, the benefit of a low first-period price $\bar{p}$ resulting from price competition outweighs the high probability of acquiring a low-quality product for consumers. Trade occurs at $\bar{p}$ since the expected consumer surplus is positive. In area *C*2, both firms compete with the same price $\tilde{p}$ in the first period. They expect a positive profit because of the probability $l(1-l)$ of posting a monopoly price in period 2. In area *C*3, one firm will post $\tilde{p}$ and the other firm will post a higher price $\tilde{p}+e$, not entering the market in the first period and betting on capturing the whole demand in the second period, should the first period seller turn out to be of low quality.

Pricing Strategies When the Domestic Firm Detects Product Quality

Now, consider the case where the domestic firm decides to detect its quality. If it turns out to be of high quality, it posts a first-period price $\bar{p}-e$, i.e., the highest price that is not imitable by a seller of unknown quality. At this price, all consumers purchase from the domestic firm in period 1. In the second period, the threat of consumers turning to the foreign firm limits the price set by the domestic firm to p_2 defined by equation (7). The expected profit of the domestic firm is therefore

$$\Pi_{test} = nl(\bar{p} - e - c + d(p_2 - c)) - k = \begin{cases} nd(q_h - c)l[1 - 2l(1-l)] - nle - k & \text{if} \quad l \leq c/q_h \\ ndl(1-l)[2lc + (1-2l)q_h] - nle - k & \text{if} \quad l > c/q_h \end{cases} . \quad (11)$$

The foreign firm expects to be driven out of the market if its competitor signals its high-quality product. Consequently, it will select a price that will make it possible to capture consumers' demand if the domestic firm turns out to offer low quality. The foreign firm's optimal strategy is therefore to post $c - e$ if it is lower than the consumers' willingness to pay (area B3), to post lq_h otherwise if it allows positive profits (area B2), and to post no price in other cases (area B1).

Detection or Nondetection Strategy

The described pricing strategies provide conditions under which the domestic firm decides whether or not to detect its quality. Proposition 3 describes the firm's decisions.

PROPOSITION 3. *The domestic firm detects its quality in areas B1, B2, and B3 of Figure 2. It signals its high quality by a price* $\bar{p} - e$ *or posts no price if it is of low quality. In areas A, C1, C2, and C3, the domestic firm does not detect quality and its price strategies are given in Proposition 2. (See the proof in Appendix B).*

In areas *B*1, *B*2, and *B*3, the domestic firm has an incentive to detect its products for driving out the foreign firm of the market, which occurs with domestic high-quality products. In *B*1, the foreign firm never enters the market, and in *B*2 and *B*3, it sells its product only if the domestic one is of low quality.

Welfare Effects of Trade Liberalization

We now turn to the comparison of signaling strategies and welfare between autarky and free trade. Trade liberalization modifies the range of parameters for which the domestic firm signals its quality. Figure 3 shows that under free trade, the area where the domestic firm signals its quality is larger in the l dimension and smaller in the k dimension. In areas b and *B*3, opening borders results in quality revelation under free

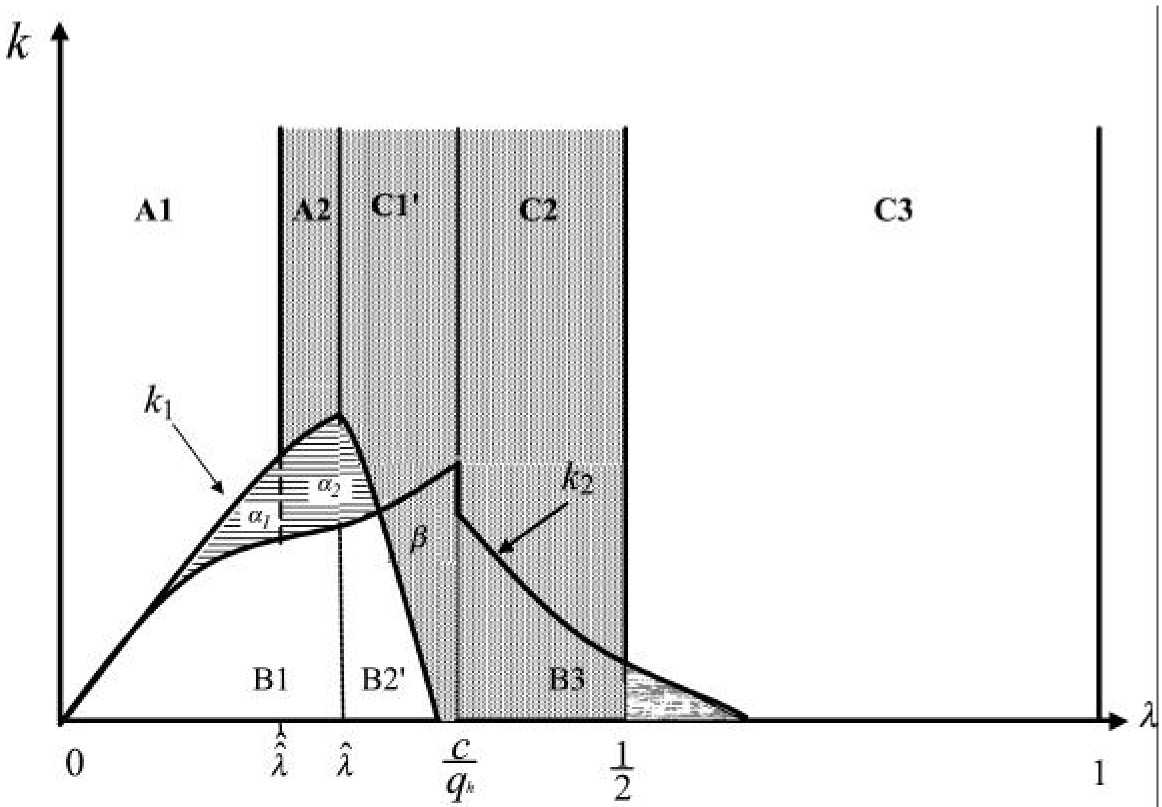

FIGURE 3. Welfare implications of trade liberalization, northern country

trade, while this was not the case under autarky. Competition with a foreign firm provides an incentive for acquiring more information for the domestic firm, because detection helps to drive the foreign firm out of the market if the domestic firm is of high quality. On the other hand, in areas a_1 and a_2, free trade results in nonrevelation when there was revelation under autarky. The reason is that trade liberalization increases the first-period loss necessary to credibly signal quality.

In Figure 3, domestic welfare remains unchanged in the white area, decreases in the hatched area, and increases in the gray area when trade is liberalized. In areas *A*1, *B*1, *B*2' and *C*3 (white area), trade liberalization may result in a transfer from the domestic firm to consumers, but the strategies of detection and signaling remain unchanged. That is, domestic welfare is the same when imports are either banned or allowed. In areas a_1 and a_2, (hatched area), the overall domestic welfare decreases with trade liberalization. In a_1 the domestic firm does not supply the market, and in area a_2 it does not detect its quality under free trade, while it used to do so in autarky. In areas b and $B3$, trade liberalization benefits the domestic country for two reasons. First, competition compels the domestic firm to detect and signal product quality (this holds for values of l, which resulted in the absence of detection under autarky). This has a positive effect on welfare. Second, the consumer is now able to capture a strictly positive surplus from trading with the foreign firm (area $B3$) when the domestic firm failed to offer high-quality products. In area $C1$' and $C2$, trade liberalization also results in an increase in domestic welfare. Competition in period 1 leads to detecting quality of both the domestic and foreign firms. Consumers benefit from the extra information, since at the end of period 1 they have tested two products rather than only one under autarky. Finally, in area $A2$, trade liberalization also leads to an increase in domestic welfare. Under autarky there was a market closure, while under free trade the domestic welfare is similar to that in area C. Free trade makes market closure less likely to happen (market closure is limited to values of l below $\hat{\hat{\imath}}$, with $\hat{\hat{\imath}} < \hat{\imath}$; see Appendix B). Appendix C provides the value of the welfare in the different areas in figure 3.

Robustness and Extensions

In defining the analytical framework, we made restrictive assumptions in order to focus on the effects of trade liberalization on quality revelation mechanisms. While the shape and the size of the various areas in the figures differ, most basic mechanisms remain unchanged when we introduce the following changes:

1. *Different production costs and different l according to the origin.* This introduces some comparative advantage in the analysis, makes it possible to integrate more realistic (but more classical) sources of gain from trade, but does not alter the mechanisms illustrated here;
2. *A more elastic demand.* A consequence is that an increase of welfare coming from trade liberalization may appear in areas $a1$ and $a2$ in Figure 3, when the reduction of the deadweight loss outweighs the absence of quality detection. It means that trade liberalization would more often have positive effects for a country in spite of trading with a country with an informational handicap;

3. *A different willingness to pay for safety across countries.* This could be taken into account by studying a bilateral opening context. Under our assumptions, consumers in the foreign country would also benefit from trade liberalization, and the domestic firm would have more possibility for quality revelation due to a larger market for the same fixed cost of detection;
4. *The case where buyers can observe the result of the quality test (linked to a public process for labeling or certification).* This obviously modifies the need for price signaling and subsequently the results on prices and welfare. However, this assumption does not modify the nature of the results regarding the link between competition and revelation.

The case of a more competitive structure could also be treated within this framework. Under the above assumptions, it is noteworthy that if several foreign firms enter the domestic market, trade liberalization would lead to a greater incentive for a firm to reveal quality due to the competition pressure, as profits in the absence of detection tend toward zero.

Conclusion

Using a stylized representation of reality, we highlighted some economic mechanisms that operate when there is a possibility of trading contaminated products and their possible consequences for trade policy. We showed that opening a country's market to imports of unknown quality may have a positive effect on domestic welfare, in the absence of comparative advantage in production costs and economies of scale, with similar average product quality in both countries, even when the foreign country is characterized by an informational handicap. However, trade liberalization results in a higher cost for the domestic firm to signal its product quality. It may lead to a decrease in domestic welfare when the probability of acquiring safe products is low, when the cost of quality control is high, and when the domestic firm facing competition is deterred from detecting its product quality. Imports of unknown quality may expand the possibility for market closure and for commercialization of tainted products simply because of information effects.

Even though the empirical lessons that can be drawn from this exercise are limited by the assumptions that were made for keeping the model simple, the finding that opening the market to imports may result in an increase in the welfare of the importing country deserves more exploration in the present debate on trade liberalization.[8]

In the food sector, decisionmakers face criticism from consumer groups when they allow import of tainted products from developing countries that lack sophisticated infrastructures for safety control. They also face complaints from developing countries, which argue that rich countries' quality detection and certification requirements act as nontariff barriers. Several empirical cases have shown that quality certification requirements were major impediments to developing countries' exports, with very marginal impacts on consumer protection.[9] Because vested interests are often hidden in the guise of consumer protection, and because of the need to grant developing countries fair access to markets, several economists recently have argued for more cost-benefit analysis in defining sanitary and phytosanitary rules for imports (Anderson, McRae, and Wilson 2001). In such future analyses, the effect of potential or actual competition from foreign producers on quality detection should be considered.

There is evidence that competition from imports has provided an incentive for informational differentiation. During the last few years, EU firms have made an increasing use of labels and certifications and have signaled the absence of genetic engineering and respect for ethical or environmental standards as a way to differentiate themselves and to cope with lower tariffs. Not all of these cases correspond to the assumptions considered in this paper, but several of the mechanisms illustrated here remain valid in a more realistic economy where sellers are not always informed of product quality by suppliers. The fact that, in this stylized framework, consumers benefit from having more information compared to the case under autarky suggests that more consideration should be given to informational effects when assessing the gains of trade liberalization.

Endnotes

1. The ability to detect and/or identify pathogens is a frequent obstacle for southern countries to comply with northern countries' standards. For example, when the European Union notified the World Trade Organization that it would seek lower levels of aflatoxin in imported food, India and several other developing countries complained that they did not have the technology for detecting such low levels. It is estimated that the EU requirement will reduce African exports of cereals, dried fruits, and nuts to Europe by two-thirds (World Bank 2001). More generally, the Bank estimates that the creation of an administrative system for compliance, conformity assessment, quality testing, and certification is the largest potential obstacle for developing exporters, among technical standards.

2. The assumption that the probability of producing low-quality products is higher in the "southern" country is not supported by evidence. Data from U.S. public agencies show that food imports are no more frequently tainted than are domestic food products. For some contaminants (chemical residues), imports even turn out to be less frequently tainted (Stark 1999).

3. The assumption that quality is structurally linked to the plant or the production process and that quality detection relies on the testing on the installations and equipments is consistent with the main procedure used in the food sector, the Hazard Analysis at Critical Control Point (HACCP), which relies on monitoring sanitation procedures at different stages of the production process. This is also the main assumption behind ISO9000 (International Standardization Office) certification. Unlike our simplified model, neither HACCP nor ISO certification provides a 100 percent probability that the product will be of high quality.

4. Many safety/quality tests are conducted during the process of production and are difficult to communicate to consumers. This is the case with the HACCP procedure. Moreover, most of the time, consumers do not have the opportunity to inspect plants.

5. Any price higher than the marginal cost could be selected by a low-quality seller. There is no possibility for a price higher than the perfect-information price (i.e., q_h) to signal high-quality products, which differs from the framework used by Bagwell and Staiger (1989), Bagwell and Riordan (1991) or Ellingsen (1997).

6. The second period price p_2 is the threshold price that makes consumers indifferent between purchasing high-quality products from firm *i* and products of uncertain quality from firm *j*, sold at price *c*. The expression of p_2 comes from the constraint $q_h - p_2 = l q_h - c$ *for* $l > c/q_h$. For $l < c/q_h$, no consumer is ready to buy products of uncertain quality, so that the high-quality seller can post a price $p_2 = q_h$.

7. We restrict our analysis to cases where $\tilde{p} > \overline{p}$, namely, for $q_h > 2c$. It means that posting $\tilde{p}$ allows a positive expected profit. This condition insures the equilibrium existence. If $\tilde{p} > \overline{p}$ an inexistence of equilibrium arises. Indeed, firms increase their profits by decreasing prices (i.e., capturing the whole demand) until reaching $\overline{p}$, where intertemporal profits are zero. However, this is not an equilibrium, because each firm has a unilateral incentive to increase price. This strategy leads to the absence of sales in the first period and to a positive expected profit in the second period if the other firm fails to provide high-quality goods.

8. Note that in cases where trade liberalization results in a decrease in welfare, i.e., areas $a1$ and $a2$ in Figure 3, one could consider appropriate public intervention, such as subsidies to the detection costs.

9. Examples include the EU requirement of plant certifications in the fish sector in Eastern Africa (Henson, Brouder, and Mitullah 2000); U.S. requirements for HACCP certification of meat and seafood products (Cato and Dos Santos 1998); and EU requirements for the detection of aflatoxin residues that might statistically avoid 1.4 liver cancer deaths in a billion but cause a 72 percent drop in African exports of peanuts (Otsuki, Wilson, and Sewadeh 1999).

Appendix A: Autarky

Proof of Proposition 1

Under our assumptions, the domestic firm selects a strategy expected to be the most profitable, between (*i*) production without detection, (*ii*) detection and production if high quality, and (*iii*) no quality detection or production. Given the price strategies described in the autarky section, the absence of detection results in an expected profit Π_C given by equation (1). Detection allows an expected profit Π_B given by equation (3), and no production results in a zero profit. The comparison of profits leads to

$$\Pi_B \geq 0 \Leftrightarrow k < l\, n(1 - l)d\,(q_h - c), \tag{12}$$

$$\Pi_B \geq \Pi_C \Leftrightarrow k < n\left[c - \lambda q_h - \lambda^2 \delta(q_h c)\right], \tag{13}$$

$$\Pi_C \geq 0 \Leftrightarrow \lambda \geq \hat{\lambda} = \frac{c}{q_h + \delta(q_h - c)}. \tag{14}$$

Detection is selected if conditions (12) and (13) are satisfied, which is equivalent to $k<k_1=Min[\, l\, n(1- l)d(q_h-c),\ n(c- l\, q_h- l^2\delta(q_h-c))]$, and which is verified in area B in Figure 1. Production without detection is selected if equation (13) is violated and equation (14) is satisfied, which corresponds to area C in Figure 1. Market closure emerges when equations (12) and (14) are violated, which corresponds to area A. This is expressed in Proposition 1. The equilibrium strategies are consistent with the elimination of out-of-equilibrium strategies according to the Malaith, Okino-Fujiwara, and Postlewaite (1993) refinement criterion (see also Overgaard 1993).

Appendix B: Trade Liberalization

Proof of Proposition 2

Betting on second-period profits to avoid direct price competition is only possible if $l\, q_h > c$. If $l < c/q_h$, firms compete in the first period and post $\overline{p} = c - 2\lambda(1-\lambda)\delta(q_h - c)$ so that expected intertemporal profits are zero. Trade at this price is possible if the expected consumer surplus *SC* is nonnegative: $SC(\overline{p}) = n\left[\lambda q_h - \overline{p} + \lambda^2\delta(q_h - c)\right] \geq 0 \Leftrightarrow \lambda \geq \hat{\hat{\lambda}}$ where $\hat{\hat{\lambda}}$ is defined by equation (15). If $\lambda < \hat{\hat{\lambda}}$, the price $\overline{p}$ does not allow consumers to expect a positive surplus, and there is a market closure:

$$\hat{\hat{\lambda}} = \frac{q_h + 2\delta(q_h - c) - \sqrt{[q_h + 2\delta(q_h - c)]^2 - 4\delta c(q_h - c)}}{2\delta(q_h - c)}\ . \tag{15}$$

If $\lambda > c/q_h$, inter temporal strategies are possible. By definition of $\tilde{p}$, competing firms have no incentive to set a price below $\tilde{p}$, as it would lead to lower profits than the "betting on second period" strategy. Depending on the probability of remaining present in the second period, two possible equilibria must be considered:

(*i*) the market sharing equilibrium, when both firms post price $\tilde{p}$ and get the same positive profit π^D given by equation (16). π^D is positive because $\tilde{p} > \overline{p}$, the break-even price under duopoly (see endnote 9):

$$p^D(\tilde{p}) = \frac{n}{2}(\tilde{p} - c) + n\, l\,(1 - l)\, d\,(q_h - c)\ ; \tag{16}$$

(*ii*) the "temporal differentiation equilibrium," when one firm posts $\tilde{p}$ and the other posts $\tilde{p} + \varepsilon$, a case where both firms expect the same positive profit π_j given by equation (9).

It is easy to see that $\pi^D(\tilde{p}) > \pi_j \Leftrightarrow \lambda < 1/2$. Under this condition, $(\tilde{p}, \tilde{p})$ is the equilibrium and both firms expect a positive profit $\pi^D(\tilde{p}) > \pi_j$. By posting any lower price $\tilde{p} - K$, the firm *i* captures the whole demand but obtains a profit $\pi_i(\tilde{p} - K) = \pi_j - nK$, with π_j given by equation (9). As $\pi_j < \pi^D(\tilde{p})$, lowering prices is not a profitable deviation. By posting any higher price $\tilde{p} + K$, the firm *j*, betting on second-period profits, obtains a profit $\pi_j < \pi^D(\tilde{p})$ and therefore has no incentive to deviate from price $\tilde{p}$.

If $\lambda > 1/2$, $\pi^D(\tilde{p}) < \pi_j$, the situation where firm *i* posts $\tilde{p}$ and firm *j* posts $\tilde{p} + \varepsilon$, both expecting a profit π_j, is an equilibrium. Firm *j* has no incentive to post price $\tilde{p}$ as it would allow a profit $\pi^D(\tilde{p}) < \pi_j$. Cutting the price even more (in order to catch the whole demand) and posting any price $\tilde{p}$ -*K* results in a profit $\pi(\tilde{p}-K)=n(\tilde{p}-K-c+\lambda(1-\lambda)q_h)=\pi_j$ -nK< π_j . Firm *i* cannot imitate firm *j* and post $\tilde{p}+\varepsilon$, because its profit would be $\pi^D(\tilde{p}+\varepsilon)=\pi^D(\tilde{p})+(n/2)\varepsilon$, which is still lower than π_j for small values of ε (remember that $\varepsilon \to 0$ in Proposition 2). Finally, firm *i* has no incentive to set a price $\tilde{p}+K$ higher than its competitor's price because this holds its own profit constant $\pi(\tilde{p}+K)=\pi_j$ and slightly increases its competitor's profit, $\pi(\tilde{p}+\varepsilon)=\pi_j+n\varepsilon$.

Technical Explanations for Figure 2

The shift from situation (*i*) to (*ii*) in the preceding section takes place when l reaches the critical value l=1/2 as can be seen in Figure 2. The explanation lies in the opposite effects of l on expected profits. In both *C*2 and *C*3, first-period profits are negative ($\tilde{p}<c$) but the loss becomes smaller when l increases. For low values of l (area *C*2), the first-period loss is shared by the two firms, as each of them captures half of the demand in the first period. For higher levels of l (area *C*3), the single seller experiences a lower per unit loss but a larger overall loss, because it applies to the whole demand (*n* consumers). In the second period, an increase in l has two opposite effects on profits: under duopoly in area *C*2 (respectively the single seller in C3), increasing l results in a higher probability of being present in the second period and also a higher probability that the competitor is present (respectively results in a higher probability of being present in the second period but lowers the second period price that the single seller can post). These competing effects are such that second-period profits are increasing in l in the interval [c/q_h, ½] and decreasing in the interval [½,1].

Proof of Proposition 3

The domestic firm selects strategy expected to be most profitable among (*i*) no production and detection, (*ii*) production without detection, and (*iii*) detection and production if high quality. Given the price strategies described in the trade liberalization section, the absence of detection results in an expected profit Π_{C1}=0 if $l \le c/q_h$, Π_{C2} given by equation (16) if $c/q_h < l \le$½, and Π_{C3} given by equation (9) if l>½. Define the following:

$$\Pi_C=\begin{cases}\Pi_{C1} & if \quad \lambda \le c/q_h \\ \Pi_{C2} & if \quad c/q_h<\lambda<1/2 \\ \Pi_{C3} & if \quad \lambda>1/2\end{cases} \tag{17}$$

and

$$k_2 = \begin{cases} n\delta(q_h - c)\lambda(2\lambda^2 - 2\lambda + 1) & if \quad \lambda \le c / q_h \\ n\delta(1-\lambda)(-2\lambda^2(q_h - c) + \lambda c + \frac{c}{2}) & if \quad c / q_h < \lambda < 1/2 \, . \\ n\delta(1-\lambda)(-2\lambda^2(q_h - c) + c) & if \quad \lambda > 1/2 \end{cases} \tag{18}$$

Detection allows an expected profit Π_{Test} given by equation (11), and no production results in a zero profit. Π_C is always positive; however, trade without detection is only possible if consumers expect a nonnegative surplus.

$$\Pi_{Test} \ge 0 \Leftrightarrow k < n\delta(q_h - c)\lambda(2\lambda^2 - 2\lambda + 1)\,, \tag{19}$$

$$\Pi_{Test} \ge \Pi_C \Leftrightarrow k < k_2\,, \tag{20}$$

$$SC(\overline{p}) \ge 0 \Leftrightarrow \lambda \ge \hat{\hat{\lambda}}\,. \tag{21}$$

Detection is selected if conditions (19) and (20) are satisfied, which is equivalent to $k<k_2$. Production without detection is selected if equation (20) is violated and equation (21) is satisfied. Market closure emerges when equations (19) and (21) are violated. This is expressed in Proposition 3.

Appendix C: Comparison of Domestic Welfare (Based on Figure 3)

Area	Welfare Autarky	Welfare Free Trade	Change
$A1$	0	0	=
$A2$	0	$n[l q_h - c + d l (q_h - c)(2 - l)]$	+
α_1	$n l (1+d)(q_h - c) - k$	0	-
α_2	$n l (1+d)(q_h - c) - k$	$n[l q_h - c + d l (q_h - c)(2 - l)]$	-
$B1$	$n l (1+d)(q_h - c) - k$	$n l (1+d)(q_h - c) - k$	=
$B'2$	$n l (1+d)(q_h - c) - k$	$n l (1+d)(q_h - c) - k$	=
β	$n[l q_h - c + l d (q_h - c)]$	$n l (1+d)(q_h - c) - k$	+
$B3$	$n[l q_h - c + l d (q_h - c)]$	$n[l (1+d)(q_h - c) + (1 - l) d (l q_h - c + e)] - k$	+
$C'1$	$n[l q_h - c + l d (q_h - c)]$	$n[l q_h - c + d l (q_h - c)(2 - l)]$	+
$C2$	$n[l q_h - c + l d (q_h - c)]$	$n[l q_h - c + d l (q_h - c) + \frac{1}{2}(1 - l) dc]$	+
$C3$	$n[l q_h - c + l d (q_h - c)]$	$n[l q_h - c + l d (q_h - c)]$	=

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