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## Trade, GMOs, and Environmental Risk

*Are Policies Likely to Improve Welfare?*

Håkan Eggert and Mads Greaker



# Environment for Development

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## **Abstract**

Food with inputs from genetically modified organisms (GMOs) has met considerable skepticism among European Union (EU) consumers. The EU import ban on GM food has triggered a great deal of controversy and has been replaced by a mandatory labeling scheme. This study had two foci. First, we examined how different policies for the production and use of GMOs might influence the market outcome in consumer food markets. Second, we evaluated the welfare effects of the policy measures. We found that mandatory labeling often increases domestic welfare and, moreover, that in most cases it increases global welfare. On the other hand, a trade ban is more likely to decrease global welfare.

**Key Words:** Product-labeling, GMOs, protectionism, trade policy

**JEL Classifications:** H2, H7, Q2, Q28

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## Trade, GMOs, and Environmental Risk: Are Policies Likely to Improve Welfare?

Håkan Eggert and Mads Greaker\*

### 1. Introduction

With an unprecedented 60-fold increase between 1996 and 2006, the GMO (genetically modified organism) is the fastest adopted crop technology in recent history. Despite the obvious potential gains, the production of GMOs is concentrated in a few countries: the United States, Argentina, Brazil, Canada, India, China, and Paraguay provide 98 percent of global production (James 2006). In other parts of the world, the introduction of GMOs has met considerable resistance, particularly within the European countries.<sup>1</sup>

After a four-year moratorium on approving the import of new GMO food and animal feed (1999–2003), the European Union (EU) moved to a mandatory labeling scheme for GMO food products, which came into effect on April 18, 2004. Although there is no measure in the General Agreement on Tariffs and Trade that directly addresses the use of product labeling based on production methods, the World Trade Organization has generally been skeptical about mandatory product labeling on the grounds that they may be used as hidden protectionism.

In this study, we looked at how different policies on GMOs affect food market structure. Any national GMO policy will necessarily have two dimensions: an upstream component regulating domestic growing of GM crops, and a downstream component regulating the content of GM inputs in packaged food. Both dimensions of policy are important. The upstream component determines to what extent verification costs must be incurred in order to supply GMO-free food, while the downstream component may decide whether GMO-free food will be available to consumers at all.

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<sup>1</sup> The latest Eurobarometer survey, based on the responses of 25,000 citizens during 2005—approximately 1,000 individuals from each of the 25 EU member states—found that only 27% of survey participants believe that the technology behind genetically modified (GM) foods should be encouraged. Most consumers have a hard time seeing any clear benefits associated with genetically engineered crops, and the support for GM foods has decreased since the previous study in 2002 (GMO Compass 2008).

With this in mind, we considered the following GMO policies: (1) mandatory labeling of GM products with no regulation upstream, (2) mandatory labeling of GM products combined with restrictions on domestic use of GM seeds to grow crops, and (3) trade bans combined with restrictions on domestic use of GM seeds to grow crops. Even though the official policy of the EU today requires mandatory labeling, different EU countries seem to employ all three measures depending on the GM crop in question.<sup>2</sup>

A significant and substantial willingness to pay for GMO-free food was found by several studies (see e.g., Lusk et al. 2005; Carlsson et al. 2007). The reasons for the apparent public opposition can be divided into several categories: concern about the environment, food safety risk, ethical beliefs, and the concentration of ownership of these new crops in the hands of a few multinational companies (see, e.g., Moschini 2001). In addition, it can also be due to successful campaigns by “green” lobbyists or the central role that food and cooking play in European culture (Carlsson et al. 2007). The major environmental risks linked with the release of GMO to the environment include changes in genome organization, gene flow to other crops or wild relatives (Wolfenbarger and Phifer, 2000), but also effects on other native species in the surrounding ecosystems (Arriaga et al, 2006). Hence, arguments against GMO are not solely based upon environmental aspects. Still, the recent French suspension of GM maize was advocated on the basis that a scientific committee announced that it had found “new scientific facts relating to a negative impact on flora and fauna” (EurActive 2008).

The content of GM inputs in food can neither be observed before purchase nor experienced after purchase, and GMO-free food is a typical credence good (Darby and Karni 1973). Hence, there exists the potential problem of Akerlof’s (1970) famous market for lemons and peaches. If GMO food is cheaper to produce, there is a risk that only GMO food will prevail, despite the fact that there are consumers willing to pay for GMO-free food. Noussair et al. (2004) studied French consumers and found that a surplus can be gained from segregating the market for food products into a GMO-free segment and a segment allowing GMO foods.

Having compared the market effects of the different policy combinations, we asked whether policies can be classified as protectionist. Fischer and Serra (2000) defined a domestic policy measure as being protectionist when the loss in foreign welfare exceeds the domestic welfare gain from the use of the measure. For instance, if the loss in foreign

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<sup>2</sup> For instance, GM maize, type MON 810, has been the only GM crop authorized for cultivation in France. However, France is considering suspending both the marketing and cultivation of this crop in its territory. (See EurActive 2008.)

producer surplus is bigger than the gain in consumer surplus by having access to only GMO-free food instead of just GMO food, a trade ban is protectionist.

In order to properly evaluate whether a measure is protectionist, we compared the welfare gains and losses throughout the food marketing chain. In the case of GMOs, the food marketing chain consists of life science companies that provide GM seeds, farmers that grow GM crops, packaged-food companies that use GM and non-GM crops to make food products, and consumers. A body of literature has studied the effects of the introduction of GMOs on life science companies, farmers, and consumers (see, e.g., Fulton and Giannakas 2004; Lapan and Moschini 2004). Since the effects of GMO policy are also likely to depend on the actual food market in which GM inputs enter, we included the packaged-food companies.

The trade effects of GMO policies were also studied by Lapan and Moschini (2004). Because life science companies capture monopoly rents, it is possible that import restrictions on GMO food can be beneficial in terms of lower prices. Further, the use of a mandatory labeling scheme and the verification costs for GMO-free food may lead food exporting countries without domestic life science companies (e.g., in South America) to impose a ban on export of GM crops. However, Lapan and Moschini (2004) did not compare the welfare gains and losses through out the marketing chain, and thus did not evaluate whether policies were protectionist with point of departure in the definition of Fischer and Serra (2000).

Fulton and Giannakas (2004) examined the system-wide effects of introducing GMO products and compared the non-GMO case with labeling and without labeling in a closed economy. They found that consumers, producers, and life science companies rarely agree in ranking the three regimes, which implicitly indicates that governments in various countries will promote various regimes, depending on whether the country is a producer or importer of food and whether it has domestic life science companies or not. They also showed how demand for a GMO ban can be rational for consumers, compared to mandatory labeling and full compliance.

Our point of departure was some market for a packaged type of food that can be produced either with or without the use of GM inputs. Most markets for packaged food are dominated by a few producers and, hence, characterized by imperfect competition. Further, food products are often differentiated with respect to taste, texture, packaging design, etc. We built our analysis on the model in Greaker (2006), which was based on Neven and Thisse (1990). While Greaker analyzed a pure production-related environmental externality, the GMO case is a consumption-related externality, which is further complicated by the issue of verification costs.

The model involves product differentiation along two dimensions. In particular, we assumed that products are horizontally differentiated *ex ante*, and that producers choose

whether to additionally differentiate their products in a vertical dimension based on GMO content. There exists a fairly large literature analyzing consumers' demand for environmental quality in models of pure vertical differentiation (see, e.g., Arora and Gangopadhyay 1995; Bansal and Gangopadhyay 2003; and Amacher et al. 2004). In such models, firms earn zero profit without the environmental differentiation. Consequently, an analysis of GMO policy and protectionism, with point of departure in Fischer and Serra (2000), in models with only vertical differentiation would be trivial—that is, firms could only increase their profits.

We found that the market effects of GMO policy depend crucially on the cost disadvantage of GMO-free food, the strength of the consumers' taste for the product variants, and the average willingness to pay for GMO-free food. For instance, if consumers' taste for a particular variant of the product is strong, there is a tendency for producers to choose the same strategy with respect to GMO content. Hence, in case of mandatory labeling, foreign suppliers may lose profit due to verification costs. On the other hand, when consumers' taste for a particular variant of the product is weak, producers are likely to choose differently. This in fact implies that foreign producers may increase their profit due to GMO policy, even though they choose not to label their product as GMO-free! Adding gains and losses in the different cases, we also found that a mandatory labeling scheme combined with a domestic restriction on the growing of GM crops is likely not protectionist and may increase welfare.

## 2. The Model

The model is a two-stage game between a representative domestic food manufacturer and a representative foreign food manufacturer, both exporting some type of packaged food to a domestic market. The production process of the representative firms may involve the use of GM inputs. In stage 1, the domestic firm  $d$  and the foreign firm  $f$  simultaneously choose whether to use GM inputs in their production of food products. Then in stage 2, the two firms compete in prices on the domestic market. While the domestic government and the firms share complete information, domestic consumers cannot know or observe the content of GM ingredients in the food products.

As mentioned, we evaluated the outcome of three policy alternatives. In alternative A, we assumed that GM crops are grown domestically and that both firms must pay verification costs when producing GMO-free (for instance, a label fee). In alternative B, the government forbids domestic cultivation of GM crops and, hence, only the foreign firm must pay verification costs when producing GMO free. Further, if the domestic firm chooses to produce with GM inputs, it will incur transportation costs. Finally, in alternative C, firms are forced to produce without GM inputs. Moreover, as in alternative B, we assumed that only the foreign firm must pay verification costs.



### 3. Packaged Food Firms

GMOs can be used as inputs to produce many types of packaged food: cornflakes can be made from GM corn, soy oil can be extracted from GM soy beans, potato chips can be cut from GM potatoes, and tomato sauce can stem from GM tomatoes. Moreover, some regard meat from livestock that has been fed on GM fodder to be GMO food in need of labeling.

In order to make the food product in question, the firm must choose between two types of inputs: GM inputs or GMO-free inputs. Due to the desirable properties of GM crops, such as increased yields and reduced use of chemical sprays, GM ingredients are cheaper than the corresponding GMO-free ingredient. On the other hand, the cost advantage of using GM inputs will clearly depend on the food product in question.

The unit costs of the two firms are:

$$c_i = \begin{cases} c_0 & \text{if GMO free food without verification} \\ c_0 + \nu & \text{if GMO free food with verification} \\ c_g & \text{if producing GMO food from domestic GM crops} \\ c_g + \tau & \text{if producing GMO food from import of GM crops} \end{cases} \quad i = d, f, \quad (1)$$

where  $c_0 > c_g + \tau$ ,  $\nu$  is verification costs,<sup>3</sup> and  $\tau$  is a transport cost incurred only if GM inputs must be imported from the other country.<sup>4</sup> We also assume that the GMO free input is always available locally.

The profits of the firms are given by:

$$\pi_i(p_d, p_f) = (p_i - c_i)q_i(p_d, p_f), \quad i = d, f \quad (2)$$

where  $p_i$  is the price of product  $i$ ,  $c_i$  is the unit production cost of product  $i$ , and  $q_i(p_d, p_f)$  is the domestic demand for product  $i$ ,  $i = d, f$ .

Finally, we assumed that the foreign firm is serving the domestic market from a separate production unit. Thus, any changes in the input mix of this unit, will not affect the performance of the foreign firm in any other market.

<sup>3</sup> Lence and Hayes (2002) estimated verification (or in their notation, direct identity preservation[IP]), costs for grain at 10%. Another recent study held that, in addition, there are hidden costs and stressed that IP costs tend to increase in a non-linear fashion close to zero levels and may sometimes be prohibitively costly (Maltsbarger and Kalaitzandokes 2000).

<sup>4</sup> To simplify, we set the costs of transporting the packaged good from the factories to the retailers to zero for both firms. This should not have influenced our results, as this part of the transport cost is unlikely to be influenced by policy.

#### 4. Consumers

Like in the Hotelling model of horizontal differentiation (see, e.g., Tirole 1988, 279), we assumed that consumers buy only one unit of the food product in question in each period, and that the market is fully covered. Hence, total demand is equal to the number of consumers, which we normalized to 1.

In order to account for the vertical dimension of product differentiation, consumers are uniformly distributed over a unit square instead of a line of unit length, as in the Hotelling model. The locations of the consumers on the horizontal bottom line of the unit square represents their most preferred brand proliferation, i.e., a certain flavor, packaging design etc., while each consumer's preference for GMO-free food is measured along the vertical axis of the unit square.

We assumed that producers have chosen the horizontal location of their products prior to the introduction of GM inputs. The product of the domestic firm is located at  $(0,0)$ , whereas the product of the foreign firm is located at  $(1,0)$ , i.e., at each end of the bottom line in the unit square.<sup>5</sup> Let  $x \in [0,1]$  be an arbitrary location on the bottom line of the unit square. Then  $x$  is also the number of consumers in the interval  $[0, x]$ . The gross utility from consuming one unit of the domestic product located at  $(0,0)$  of a consumer located at  $x$  is:

$$u_x^d = \Gamma - \beta x^2 + \lambda_x m, \quad (3)$$

where  $\Gamma$  is the utility from consuming one unit of food, and  $\beta x^2$  is the loss in utility of not being able to get a product located at  $x$  when buying from the domestic firm at 0. The parameter  $\beta$  is often coined the *transportation cost* parameter, and the term  $\beta x^2$  the *transport costs*.

The term  $\lambda_x m$  is the benefit from consuming a GMO-free food by a consumer located at  $x$ , where  $\lambda_x$  is uniformly distributed on  $[0,1]$ . Hence,  $\frac{m}{2}$  is the average willingness to pay for GMO-free food. Note that the benefit  $\lambda_x m$  is only received if the consumer can be sure that the product is really GMO free.

Similarly, the gross utility of the consumer at  $x$  from consuming one unit of the foreign product located at  $(1,0)$  is:

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<sup>5</sup> The fact that the products are located at each end of the bottom line implies that the producers have chosen to maximize the horizontal differentiation of their products. We assumed this to be given by history, and that the horizontal location cannot be changed without incurring high fixed costs. With point of departure in the Hotelling model, it can be shown that producers will choose to maximize their product differentiation, given quadratic transportation costs (Tirole 1988, 281).

$$u_x^f = \Gamma - \beta(1 - x^2) + \lambda_x m, \quad (4)$$

where the term  $\beta(1 - x^2)$  denotes the loss in utility of not being able to get a product located at  $x$  when buying from the foreign firm.

Let  $cs$  denote individual consumer's surplus, which is the difference between consumer's willingness to pay and the price actually paid, i.e.,  $cs_x^i = u_x^i - p_i$ ,  $i = d, f$ .

Consumers make their purchase decisions by maximizing their surplus. We called the consumer who is indifferent to buying product  $d$  and product  $f$  *the marginal consumer*, and denoted the location of the marginal consumer by  $x^*$ . When products are equal with respect to GM content, we obtained for the location of the marginal consumer:

$$x^* = \frac{\beta - p_d + p_f}{2\beta}, \forall \lambda, \quad (5)$$

i.e., the location  $x^*$  is independent of  $\lambda$  and, hence, the unit square is divided by a vertical line at  $x^*$ , which for  $p_d = p_f$  divides the unit square into two identical parts of size  $\frac{1}{2}$ .

When products are different with respect to GM content, we obtained:

$$x^* = \pm \frac{m}{2\beta} \lambda_{x^*} + \frac{\beta - p_d + p_f}{2\beta}. \quad (6)$$

The sign in front of  $\frac{m}{2\beta}$  is positive when product  $d$  is GMO free and product  $f$  is GM (and negative if *vice versa*). The location of the marginal consumer  $x^*$  is now dependent of  $\lambda$  and, hence, the unit square is divided by a straight line increasing (decreasing) in  $x^*$ . If, for instance, product  $d$  is GMO free and product  $f$  is GM,  $p_d = p_f + \beta$ , and  $m = 2\beta$ , the line divides the unit square into two identical triangles of size  $\frac{1}{2}$ .

## 5. Domestic Welfare

Domestic welfare consists of consumer surplus and producer surplus. Let  $CS$  be the aggregate consumer surplus for which we have  $CS = \Gamma - TC + B - p_d q_d - p_f q_f$ , where  $TC$  is the aggregate transportation cost, that is, the aggregated loss to each consumer of not being able to buy the most preferred product in the horizontal dimension. Further,  $B$  is the aggregate benefit from consuming GMO-free food. (See appendices D and E for a complete derivation of both  $TC$  and  $B$ ). The domestic welfare function is then:

$$W_d = \Gamma - TC + B - p_d q_d - p_f q_f + \pi_d, \quad (7)$$

where the first five terms are consumer surplus, and the sixth term is the profit of the domestic firm. Notice that apart from the constant  $\Gamma$ , all the terms in equation (7) will depend on the policy choice of the domestic government.

## 6. Foreign Welfare

We assumed that the life science company is located in the foreign country. Moreover, we assumed that it does not participate in the game. Hence, profits  $\Pi$  are given as a function of total GM food sales, i.e., either  $\Pi(1)$  or  $\Pi(q_i)$  or  $\Pi(0)$  with  $\Pi' > 0$ . The market for the packaged food in question is likely small in comparison to the total sales of the type of GM crops, e.g., cornflakes using GM corn compared to the total GM corn market. Thus, it seems reasonable to assume that the pricing decision of the life science company will be independent of the market outcome in the market under study.

Moreover, we assumed that the foreign country is only concerned about the profit of the life science company and the benefit from the one-way trade, i.e., the profit of its firm  $f$  from exporting to the domestic country:

$$W_f = \Pi + \pi_f. \quad (8)$$

Land rents are not included explicitly in either the expression for domestic welfare or in the expression for foreign welfare. In some cases, farmers are vertically integrated with packaged food firms through farmers' cooperatives and, hence, land rents are a part of producer surplus. To the extent that the packaged-good firms are independent-buying intermediates from farmers, it seemed reasonable to assume that land rents are not influenced by the use of GM inputs in any particular packaged food market.<sup>6</sup>

## 7. The Effect of GMO Policies on Market Outcome

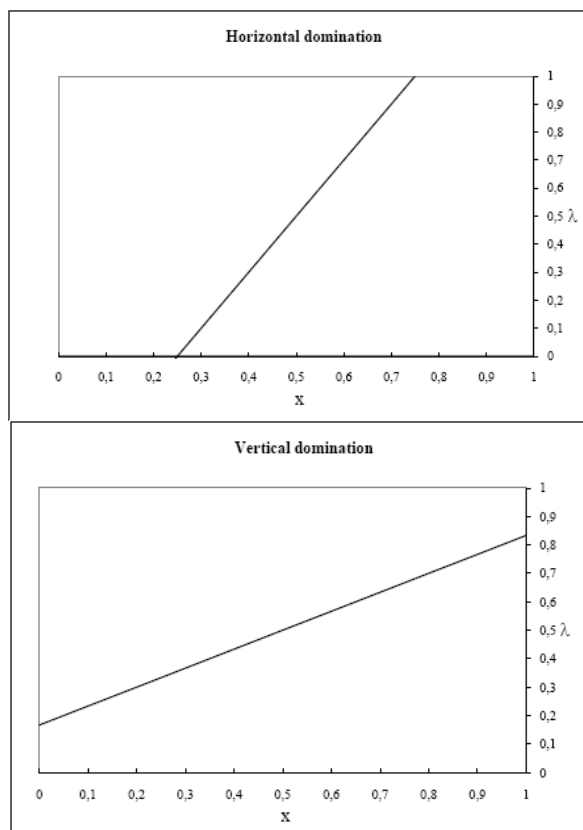
We compared the following GMO policies: (1) mandatory labeling of GM products with no regulation upstream, (2) mandatory labeling of GM products combined with restrictions on domestic use of GM seeds to grow crops, and (3) a trade ban combined with restrictions on domestic use of GM seeds to grow crops. With respect to policies A and B, producers may choose differently with respect to labeling their product as containing GM. It then turns out that the market outcome depends crucially on consumers' *ex ante* preferences

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<sup>6</sup> The marginal farmer will be indifferent between choosing GM seeds and traditional seeds. (See, for instance, Fulton and Giannakas 2004). Moreover, what happens in one particular food market can only have marginal effects on the supply of GM inputs.

for the brand proliferation of the products variants. As discussed by Neven and Thisse (1990), we could have either horizontal domination or vertical domination, which refers to how the two firms divide the market.

**Figure 1. The Division of the Market**



In figure 1, the domestic firm produces GMO free and the foreign firm produces with GM inputs, hence,  $p_d > p_f$ . All the consumers to the left of the line defined by (6) buy the domestic product, whereas all the consumers to the right of the line buy the foreign product. If consumers have strong preferences for either of the two brand proliferations — i.e.,  $\beta$  is high compared to  $m$  such that  $\frac{m}{2\beta} < 1$  — the market will be divided as in the left part of the figure labeled “horizontal domination.” When consumers have weak preferences for either of the two brand proliferations— i.e.,  $\frac{m}{2\beta} > 1$  — the market will be divided as in the right part of the figure labeled “vertical domination.”

Note that in the vertical domination case, consumers placed at the right end of the bottom line may still buy from the domestic firm at the left end of the bottom line, provided

that their  $\lambda$  is above  $\approx 0.84$  (the intersection of the line (6) with the  $\lambda$ -axis). On the other hand, in the horizontal domination case, some consumers will always buy from the domestic firm and some consumers will always buy from the foreign firm. In other words, they care so much for their chosen brand that the issue of GM content does not matter independent of their  $\lambda$ . This difference turns out to be important when calculating the optimal GMO free label adoption strategies of the firms.

The transportation cost parameter  $\beta$  can be normalized to 1 without loss of generality, so it will be suppressed in the remaining part of this paper.

## 8. Market Outcome under Horizontal Domination

One example of horizontally dominated demand could be breakfast cereals made from GMO-free or GM corn, or pasta made from GM or GMO-free wheat. Since  $\beta$  is fixed to unity,  $m \in \left(0, \frac{3}{2}\right]$  ensures that we have horizontal domination. Further, let  $0 < (c_0 + v - c_g) \leq \frac{3}{2}$ , which ensures that the analytical solution to the game is tractable (see appendix B2).

### 8.1 The Second Stage: The Bertrand Equilibrium

There are four possible market outcomes: either both firms produce GMO free, or both produce with GM, or firms choose differently with respect to GM content. In the two former cases, there is only horizontal differentiation in products  $d$  and  $f$ , and the model is identical to the Hotelling model (see, e.g., Tirole 1988, 279).

When firms choose differently with respect to GM content, products  $d$  and  $f$  are differentiated in both the horizontal and vertical dimension. The demand functions  $q_i(p_d, p_f), i = d, f$  are then composed by three segments, and the unique Bertrand-Nash equilibrium will be found in the intermediate segment (see appendix A2 for the derivation of demand functions). The Nash Equilibrium profits for the different outcomes are summarized in the table 1 (see appendix B2 for the derivation).

The case in which the foreign firm produces GMO free and the domestic firm produces with GM is just a mirror image of the bottom row in table 1.

**Table 1. NashEquilibrium Profit**

Market outcome	Domestic firm profit	Foreign firm profit
Both GM/GMO free	$\frac{1}{2} \left( \frac{3 - c_d + c_f}{3} \right)^2$	$\frac{1}{2} \left( \frac{3 + c_d - c_f}{3} \right)^2$
Firm <i>d</i> GMO free Firm <i>f</i> GM	$\frac{1}{2} \left( \frac{3 + \frac{m}{2} - c_d + c_f}{3} \right)^2$	$\frac{1}{2} \left( \frac{3 - \frac{m}{2} + c_d - c_f}{3} \right)^2$

**8.2 The First Stage: GM or GMO Free**

Both firms have two pure strategies in their strategy spaces: to use GMO-free or GM inputs and the payoffs are simply the associated profits. Given the willingness to pay for GMO-free food, the choice of strategy will depend on the cost disadvantage of producing GMO free in that particular market,  $c_0 + v - c_g$  (see Appendix C). Define  $l_l^w = \frac{m}{2}$  and  $l_h^w = \frac{m}{2} + v + \tau$ . Note that  $l_l^w < l_h^w$ , and observe that both  $l_l^w$  and  $l_h^w$  increase in  $m$ . We then have the following possible market outcomes seen in table 2.

**Table 2. Second-Stage NashEquilibriums**

Market outcome	Alternative A	Alternative B
Both GMO free	$c_0 + v - c_g \leq l_l^w$	$c_0 + v - c_g \leq l_l^w$
Firm <i>d</i> GMO free Firm <i>f</i> GM	—	$c_0 + v - c_g \in \langle l_l^w, l_h^w \rangle$
Both GM	$c_0 + v - c_g > l_l^w$	$c_0 + v - c_g > l_h^w$

Note that there is always a unique equilibrium. We wrote that the cost disadvantage of GMO-free food is high, intermediate, or low, when  $c_0 + v - c_g > l_h^w$ ,  $c_0 + v - c_g \in \langle l_l^w, l_h^w \rangle$ , and  $c_0 + v - c_g \leq l_l^w$ , respectively. Thus, in case of horizontal domination, we have that:

**Proposition:** (1) Only mandatory labeling combined with restrictions on domestic growing of GM crops may lead firms to choose differently with respect to GM inputs, and then only when the cost disadvantage of GMO-free food is intermediate; (2) if the average willingness to pay for GMO free food  $\frac{m}{2}$  is high compared to the cost disadvantage of GMO-free food, firms will tend to choose GMO-free inputs; and (3) if the average willingness to pay for

GMO-free food  $\frac{m}{2}$  is low compared to the cost disadvantage of GMO free food, firms will tend to choose GM inputs.

**Corollary 1** : If the average willingness to pay for GMO-free food  $\frac{m}{2}$  for some reason increases (decreases) compared to the cost disadvantage of GMO-free food, the market outcome will tend to yield only GMO-free food (only GM food).

When choosing whether to be different from the rival firm or to be equal to the rival firm in the vertical dimension, there are two opposing effects—the demand effect and the strategic effect. The demand effect tells the firms to be where the market is, i.e., if the willingness to pay for GMO-free food  $\frac{m}{2}$  is high compared to the cost disadvantage of producing GMO-free food, both firms should produce GMO free. On the other hand, this intensifies price competition, and the strategic effect tells the firms to stay different in order to make price competition less fierce. With horizontal domination, the demand effect is strongest, and we see that unless  $c_o + v - c_g \in \langle l_l^w, l_h^w \rangle$  and the chosen policy is alternative B, firms will stay identical in the vertical dimension.

Policy alternative A keeps firms symmetric, while alternative B introduces a cost asymmetry, which both makes it cheaper for the domestic firm to produce GMO free and more costly to produce with GM, due to the domestic restriction on the growing of GM crops. This is the reason firms choose differently when the cost disadvantage of producing GMO free is intermediate. However, due to the verification cost, the foreign firm will in most cases lose profits in case of alternative B compared to alternative A.

## 9. Market Outcome under Vertical Domination

If consumers do not have strong tastes for any of the products, demand is likely to be vertically dominated. One example of this could be cans of corn. In our model, vertical domination occurs when  $m > 2$  (remember that the horizontal differentiation parameter  $\beta$  is fixed at unity). In appendix B3, we have solved the model for the case in which  $m \geq 3$  and  $0 < (c_o + v - c_g) \leq 3$ , which ensures that we have vertical domination and makes the analysis of the model tractable.

### 9.1 The Second Stage: The Bertrand Equilibrium

Note that if both firms produce GMO free, or both firms produce with GM inputs, profits are as in the horizontal domination case, in table 1. Table 3 then gives the NashEquilibrium profits of the domestic and foreign firm in the two remaining scenarios.



**Table 3. NashEquilibrium Profit with Vertical Domination**

Market outcome	Domestic firm profit	Foreign firm profit
Firm $d$ GMO free	$\frac{(2m - c_d + c_f)^2}{9m}$	$\frac{(m + c_d - c_f)^2}{9m}$
Firm $f$ GM		

As above, the case in which the foreign firm produces GMO free and the domestic firm produces with GM is just a mirror image of the bottom row in table 3. More important, for the case when firms choose differently, note that the profits are increasing in the willingness to pay for GMO-free food, irrespective of whether the firms choose to produce GMO free or not. This implies:

**Proposition:** If the average willingness to pay for GMO-free food is higher than the difference in production cost, i.e.,  $\frac{m}{2} \geq c_0 + v - c_g$ , the foreign firm will have higher profits after the introduction of a GMO policy, even though it continues to produce with GM inputs.

**Proof:** The proposition holds if  $\frac{(m + c_d - c_f)^2}{9m} > \frac{1}{2}$ . By inserting  $c_d = c_0 + v$ ,  $c_f = c_g$ , and  $\frac{m}{2} = c_0 + v - c_g$ , it is easy to see that the proposition holds.

## 9.2 The First Stage: GM or GMO Free

The asymmetric NashEquilibrium in the second stage of the game may no longer be unique. For certain parameter values, we have two NashEquilibria: one in which the domestic firm chooses to produce GMO free and the foreign firm does not, and one in which the foreign firm chooses to produce GMO free and the domestic firm does not. Since we are interested in protectionism, we focused on the one in which the domestic firm chooses to produce GMO free (see appendix C for more details).

Define  $l_l^v = \sqrt{\frac{9m}{2}} - m - v\sqrt{\frac{m-2}{2}}$  and  $l_h^v = 2m - \sqrt{\frac{9m}{2}} + \tau\sqrt{\frac{m}{2}} + v$ . Note that  $l_l^v < l_l^h$ , and, more importantly, that  $\frac{\partial l_l^v}{\partial m} < 0$ , while  $\frac{\partial l_h^v}{\partial m} > 0$ . This implies that the interval  $[l_l^v, l_h^v]$  grows larger if the willingness to pay for GMO-free food increases compared to the cost disadvantage of GMO-free food. Three of the four possible market outcomes are depicted in table 4.

**Table 4. Second-Stage NashEquilibria with Alternatives A and B**

Market outcome	Alternative A	Alternative B
Both GMO free	$(c_0 + v - c_g) \leq l_l^v + v\sqrt{\frac{m}{2}}$	$(c_0 + v - c_g) \leq l_l^v$
Firm <i>d</i> GMO free Firm <i>f</i> GM	$(c_0 + v - c_g) \in \left\langle l_l^v + v\sqrt{\frac{m}{2}}, l_h^v - \tau\sqrt{\frac{m}{2}} \right\rangle$	$(c_0 + v - c_g) \in \left\langle l_l^v, l_h^v \right\rangle$
Both GM	$(c_0 + v - c_g) > l_h^v - \tau\sqrt{\frac{m}{2}}$	$(c_0 + v - c_g) > l_h^v$

Similarly, as in the horizontal domination case, we will say that the cost disadvantage of GMO-free food is low when  $(c_0 + v - c_g) \leq l_l^v$ , intermediate when  $(c_0 + v - c_g) \in \left\langle l_l^v, l_h^v \right\rangle$ , and high when  $(c_0 + v - c_g) > l_h^v$ . Hence, in case of vertical domination, we have that:

**Proposition:** (1) Both policy alternatives A and B may lead firms to choose differently with respect to GM inputs; (2) if the willingness to pay for GMO free food is high compared to the cost disadvantage of GMO free food, firms will tend to choose differently with respect to GM inputs; and (3) if the willingness to pay for GMO-free food is low compared to the cost disadvantage of GMO free food, firms will tend to choose GM inputs.

Note the differences from horizontal domination. When the willingness to pay for GMO-free products is high, the interval  $\left\langle l_l^v, l_h^v \right\rangle$  grows larger, and only one firm tends to choose to produce GMO-free, irrespective of policy. Thus, with vertical domination, it is the strategic effect that dominates (see corollary 1 on page 12).

### 10. Which Policies Are Protectionist?

We asked whether the policies mandatory labeling scheme and/or trade ban is likely to be protectionist. As mentioned, Fischer and Serra (2000) defined a domestic policy measure to be protectionist when the use of the instrument in question is different from what a planner would impose if all producers were local. In our setting, this amounted to comparing foreign and domestic welfare for the three policy alternatives with welfare under a “no policy” scenario. If changing from “no policy” to one of the policy alternatives implies that the foreign loss in welfare is higher than the domestic gain in welfare, we would say that the change in policy is protectionist.

We did not consider the market equilibrium in a no-policy scenario. One possibility is that labeling of GMO-free products will not emerge independent of the cost disadvantage of GMO-free food and the willingness to pay for GMO-free food. The market outcome will then always be as when the cost disadvantage of GMO-free food is high—that is, only GM

products and both firms earn profit equal to  $\frac{1}{2}$ . On the other hand, for eco-labeled products, there exist a diversity of private initiatives, such as the German Blue Angel, the Japanese Eco-Mark, the Canadian Environmental Choice, and the Nordic Swan, etc. (OECD 1997). Hence, our point of departure was that a voluntary labeling scheme for GMO-free food will emerge, provided that the average willingness to pay for GMO-free food is adequate.

Clearly, private labeling of GMO-free products would yield the same market outcome as mandatory labeling of GMO products, as long as there is no regulation upstream and both firms pay verification costs when producing GMO free. In this case, policy alternative A cannot be protectionist as long as it simply replicates “no regulation.” Further, evaluating whether policy alternative B is protectionist can be done by simply comparing the market outcome with policy alternative A. This is the route that is followed here, also with respect to policy alternative C, when both firms are forced to produce without GM inputs. In addition, we also comment here on the other case, that is, no private GMO-free labeling scheme emerges. We first evaluated the horizontal domination case.

**10.1 Welfare Effects with Horizontal Domination**

**Case 1: The cost disadvantage of GMO-free food is low**

In this section, we look at the changes in welfare. First, we studied the profit of firms when  $c_0 + v - c_g \leq l_f^w$ . As can be seen in table 2 above, firms choose to produce GMO free for all policy alternatives, and the profits are:

	Alternative A	Alternative B	Alternative C
$\pi_d$	$\frac{1}{2}$	$\frac{1}{2} \left( \frac{3+v}{3} \right)^2$	As Alt. B
$\pi_f$	$\frac{1}{2}$	$\frac{1}{2} \left( \frac{3-v}{3} \right)^2$	As Alt. B

Note that the foreign firm prefers alternative A. This is due to the verification costs, which in this case applies to both firms. Whereas in policy alternatives B and C, the verification cost only applies to the foreign firm.

Denote  $\bar{\Gamma} = \Gamma - \frac{1}{12} - 1$ . Consumer surplus is then given by:

	Alternative A	Alternative B	Alternative C
CS	$\bar{\Gamma} + \frac{m}{2} - c_0 - \nu$	$\bar{\Gamma} + \frac{m}{2} - c_0 - \frac{\nu}{2} + \frac{\nu^2}{36}$	As Alternative B

Consumer surplus is clearly higher in alternatives B and C. This is due to the saving in verification costs when there are domestic restrictions on the growing of GM crops. The following proposition compares the gains and losses:

**Proposition:** When cost disadvantage of GMO-free food is low, neither a mandatory labeling scheme combined with restrictions on domestic growing of GM crops nor a trade ban is protectionist.

**Proof:** Welfare in alternative A is equal to  $\bar{\Gamma} + \frac{m}{2} - c_0 - \nu + \frac{1}{2}$ , while welfare in alternative B and in alternative C is equal to  $\bar{\Gamma} + \frac{m}{2} - c_0 - \frac{\nu}{6} + \frac{\nu^2}{12} + \frac{1}{2}$ . The gain in welfare is equal to  $\frac{5\nu}{6} + \frac{\nu^2}{12}$ . The foreign loss is equal to  $\frac{\nu}{3} - \frac{\nu^2}{18}$ , which clearly is smaller than the domestic gain.

In all cases the life science company has profits  $\pi(0)$  and, hence, the policy alternatives do not differ with respect to the life science company.

Note that if “no policy” implied no labeling, both firms would still have profit  $\frac{1}{2}$  as in policy alternative A. However, domestic consumers would lose, while the foreign life science company would gain. It is thus hard to say whether policies are protectionist in this case.

**Case 2: The cost disadvantage of GMO free food is high**

In this case, as can be seen from table 2 when  $c_0 + \nu - c_g > l_h^w$ , firms choose to produce with GMO for both policy alternatives A and B. The profits are then given by:

	Alternative A	Alternative B	Alternative C
$\pi_d$	$\frac{1}{2}$	$\frac{1}{2} \left( \frac{3-\tau}{3} \right)^2$	$\frac{1}{2} \left( \frac{3+\nu}{3} \right)^2$
$\pi_f$	$\frac{1}{2}$	$\frac{1}{2} \left( \frac{3+\tau}{3} \right)^2$	$\frac{1}{2} \left( \frac{3-\nu}{3} \right)^2$

In this case, the foreign firm prefers policy alternative B, since it implies that the domestic firm has to import GM inputs. Hence, alternative B cannot be protectionist. On the

other hand, the domestic firm prefers alternative C, since it then has a cost advantage. Again, denote  $\bar{\Gamma} = \Gamma - \frac{1}{12} - 1$ , and consumer surplus is given by:

	Alternative A	Alternative B	Alternative C
CS	$\bar{\Gamma} - c_g$	$\bar{\Gamma} - c_g - \frac{\tau}{2} + \frac{\tau^2}{36}$	$\bar{\Gamma} + \frac{m}{2} - c_0 - \frac{v}{2} + \frac{v^2}{36}$

The two expressions  $-\frac{\tau}{2} + \frac{\tau^2}{36}$  and  $-\frac{v}{2} + \frac{v^2}{36}$  must both be negative.<sup>7</sup> Further, since we have  $\frac{m}{2} < c_0 - c_g$ , with respect to consumer surplus, alternative A is clearly preferred.

By taking welfare for alternative A and subtracting welfare for alternative C, we obtain:

$\Delta w = c_0 - c_g - \frac{m}{2} + \frac{v}{6} - \frac{v^2}{12}$ . For  $v > 2$ , this expression may be negative, and alternative C is then preferred. However, the loss in profit for the foreign firm is  $\frac{v}{3} - \frac{v^2}{18}$ , which is larger than the maximum gain in welfare of choosing alternative C,  $\frac{v^2}{12} - \frac{v}{6}$ . In addition, the life science company will lose with alternative C.

**Proposition:** When the cost disadvantage of GMO-free food is high, a mandatory labeling scheme combined with restrictions on domestic growing of GM crops is not protectionist; however, a trade ban is clearly protectionist.

This proposition also holds if “no policy” implied no labeling, since both firms will produce GMO food for alternative A.

**Case 3: The cost disadvantage of GMO-free food is intermediate**

This case is relatively more complicated. From table 2, we see that both firms choose to produce with GM under alternative A. Further, for alternative B, we have that firms choose differently with respect to using GM inputs. As above, we first look at the profit of the firms:

<sup>7</sup> We must have  $\tau, v < 3$  for both firms to produce; see appendix B.

	Alternative A	Alternative B	Alternative C
$\pi_d$	$\frac{1}{2}$	$\frac{1}{2} \left( \frac{3 + \frac{m}{2} - c_0 + c_g}{3} \right)^2$	$\frac{1}{2} \left( \frac{3 + v}{3} \right)^2$
$\pi_f$	$\frac{1}{2}$	$\frac{1}{2} \left( \frac{3 - \frac{m}{2} + c_0 - c_g}{3} \right)^2$	$\frac{1}{2} \left( \frac{3 - v}{3} \right)^2$

The foreign firm prefers policy alternative B to alternative C. In alternative C, it is forced to produce GMO free; while in alternative B, it voluntarily chooses not to produce GMO free. If  $\frac{m}{2} < c_0 - c_g$ , the foreign firm also prefers alternative B to alternative A. For the domestic firm, it is vice-versa: it prefers alternative C to alternative B, and alternative A to alternative B if  $\frac{m}{2} < c_0 - c_g$ .

Again, denote  $\bar{\Gamma} = \Gamma - \frac{1}{12} - 1$ . Consumer surplus is then given by:

	Alternative A	Alternative B	Alternative C
CS	$\bar{\Gamma} - c_g$	$\bar{\Gamma} + \frac{m}{4} - \frac{c_0 + c_g}{2} - \frac{m^2 - m(c_0 - c_g) + 2(c_0 - c_g)^2}{36}$	$\bar{\Gamma} + \frac{m}{2} - c_0 - \frac{v}{2} + \frac{v^2}{36}$

Suppose  $\frac{m}{2} = c_0 - c_g$ , both firms are then indifferent to alternatives A and B.

Moreover, it can be shown that that alternative C is inferior with respect to consumer surplus. However, it is still ambiguous whether alternatives A or B yield the highest consumer surplus, and it is easy to find values for the parameters that yield both outcomes. Since the life science company prefers alternative A to alternative B and alternative B to alternative C, the likelihood of protectionism increases in the stringency of policy.

**Proposition:** When the cost disadvantage of GMO-free food is intermediate, both a mandatory labeling scheme and a trade ban could be protectionist; however, a trade ban is more likely to be protectionist.

This proposition also holds if “no policy” implied no labeling, since both firms will produce GMO food for alternative A.

### 10.2 Welfare Effects with Vertical Domination

#### Cases 1 and 2: The cost disadvantage of GMO-free food is low or high

Further, when the cost disadvantage of GMO-free food is low, i.e.,  $(c_0 + v - c_g) < \bar{l}_l$ , both firms choose to produce GMO free for alternatives A and B. Results are then again equal to the horizontal domination case; that is, neither a mandatory labeling scheme nor a trade ban is protectionist, even though the foreign firm loses profit due to the verification costs. Again, if “no policy” implied no labeling, the case for protectionism is ambiguous, since compared to no policy, domestic consumers gain and the foreign life science company would lose.

When the cost disadvantage of GMO-free food is high, i.e.,  $(c_0 + v - c_g) > \bar{l}_h$ , both firms choose to produce with GMO for alternatives A and B. Results are then equal to the horizontal domination case; that is, a mandatory labeling scheme cannot be protectionist. On the other hand, a trade ban may be protectionist. Clearly, if “no policy” implied no labeling, nothing would change since both firms will produce GMO food for alternative A.

#### Case 3: The cost disadvantage of GMO-free food is intermediate

When the cost disadvantage of GMO-free food is intermediate, i.e.,  $(c_0 + v - c_g) \in [\bar{l}_l, \bar{l}_h]$ , firms will choose differently with policy alternative B, but not necessarily with policy alternative A (see table 4). We concentrated here on the cases when both policy alternatives yield the asymmetric market outcome, i.e.,

$(c_0 + v - c_g) \in \left[ \bar{l}_l + v \sqrt{\frac{m}{2}}, \bar{l}_h - \tau \sqrt{\frac{m}{2}} \right]$ . The profits are given by:

	Alternative A	Alternative B	Alternative C
$\pi_d$	$\frac{(2m - c_0 - v + c_g)^2}{9m}$	$\frac{(2m - c_0 + c_g)^2}{9m}$	$\frac{1}{2} \left( \frac{3+v}{3} \right)^2$
$\pi_f$	$\frac{(m + c_0 + v - c_g)^2}{9m}$	$\frac{(m + c_0 - c_g)^2}{9m}$	$\frac{1}{2} \left( \frac{3-v}{3} \right)^2$

Note that when firms choose differently, the foreign firm prefers alternative A to alternative B and alternative B to alternative C because, with mandatory labeling, it voluntarily chooses to produce with GM.

Consumer surplus is then given by:

	Alternative A	Alternative B	Alternative C
CS	$\Gamma - \frac{m}{9} - \frac{10c_0 + 10v + 8c_g + 6}{18} + \frac{(c_0 + v - c_g)^2 + 3}{18m}$	$\Gamma - \frac{m}{9} - \frac{10c_0 + 8c_g + 6}{18} + \frac{(c_0 - c_g)^2 + 3}{18m}$	$\Gamma + \frac{m}{2} - c_0 - \frac{v}{2} + \frac{v^2}{36} - \frac{13}{12}$

Note that when firms choose differently, consumer surplus decreases in the willingness to pay for GMO-free products. This occurs because price competition is softened when firms become increasingly vertically differentiated. Further, consumer surplus is clearly higher for alternative B than for alternative A. This is due to the savings in verification costs when there are domestic restrictions on the growing of GM crops. However, we noted that as  $m$  increases, alternative C will yield the highest consumer surplus. With a trade ban, firms are forced to produce GMO free, and price competition is fiercer.

The GM seed supplier is clearly indifferent to policy alternatives A and B, as long as they both yield foreign production of GMO food. On the other hand, the GM seed supplier will lose on a trade ban.

**Proposition:** When the cost disadvantage of GMO-free food is intermediate, and in addition

we have  $(c_0 + v - c_g) \in \left[ \bar{l}_l + v\sqrt{\frac{m}{2}}, \bar{l}_h - \tau\sqrt{\frac{m}{2}} \right]$ , a mandatory labeling scheme combined

with restrictions on domestic growing of GM crops is not protectionist, while a trade ban

might be protectionist. If  $(c_0 + v - c_g) \in \left[ \bar{l}_l, \bar{l}_l + v\sqrt{\frac{m}{2}} \right]$  or

$(c_0 + v - c_g) \in \left[ \bar{l}_h - \tau\sqrt{\frac{m}{2}}, \bar{l}_h \right]$ , policy alternatives A and B yield different outcomes and the results are ambiguous.

It is not necessary to look at consumer surplus. It can be shown, going from alternative A to alternative B, that the loss of the foreign firm is smaller than the gain of the domestic firm due to the savings in verification cost.

Note that the proposition does not necessary hold if “no policy” implied no labeling. The life science company always prefers that both firms produce GMO food; however, both consumers and firms may loose from not being able to choose between GM food and GMO-free food.

### 11. Concluding Remarks

In this paper, we studied the link between market structure and regulatory policies, such as labeling and trade bans, and under what conditions such regulatory measures are welfare improving from a global point of view and consequently are not protectionist. Our focus was on what happens in a particular packaged-food market. As argued, actual food



markets will differ both with respect to the strength of consumers’ tastes for the different product variants, and with respect to the cost disadvantage incurred by the use of GMO-free inputs. To fully evaluate whether any of the policy alternatives is protectionist, we would have to add the welfare gains and losses from all markets, which obviously is impossible without having detailed information for every relevant food market. However, given that a private labeling scheme would emerge under a no-policy scenario, we can summarize the results in the following way in table 5.

**Table 5. “Is a Mandatory Labeling Scheme Protectionist?”**

<b>Cost disadvantage of GMO free food</b> →	<b>High</b>	<b>Intermediate</b>	<b>Low</b>
<b>Strength of band proliferation</b> ↓			
<b>Horizontal domination</b>	<b>No</b>	<b>Possible</b>	<b>No</b>
<b>Vertical domination</b>	<b>No</b>	<b>Possible</b>	<b>No</b>

The results in table 5 hold independently of the mandatory labeling scheme combined with restrictions on domestic growing of GM crops or not. Hence, without knowing the exact effect in each market, we concluded that a mandatory labeling scheme is not protectionist in a majority of cases, and is not necessarily protectionist in the rest of the cases. (It is easy to find numerical examples when it is not.) This holds at least as long as a voluntary scheme would emerge in the no-policy case. Note also that a mandatory labeling scheme combined with restrictions on domestic growing of GM crops would become less protectionist to the extent that there were environmental externalities connected to growing GM crops as, for instance, now claimed by France (see EurActive 2008 ).

A trade ban would be protectionist in far more cases. For instance, when the cost disadvantage of GMO-free food is high, a trade ban would still yield just GMO-free food, which is protectionist compared to both no policy and mandatory labeling.

There exist huge potential benefits to producers, consumers, and the environment from GM technology. At the same time, it is still disputed whether GM crops lead to increasing or decreasing use of pesticide (Carpenter et al. 2001), and there is room for improvement to maximize benefits to society while minimizing environmental risks (Marvier et al. 2008). Consumers are very sensitive to negative information related to GMOs. The StarLink case—where the U.S. Environmental Protection Agency only approved one type of GM corn for animal feed that later was discovered in human food, and which led to several law suits and a one year 7-percent price reduction in U.S. corn exports—is a recent dramatic example (Carter and Smith 2007). The persistent and even increasing resistance to GMO food

among Europeans, paired with our results, indicates that the current mandatory labeling within EU may be welfare improving.

At the same time, we noted that consumer resistance towards GMO food can be mitigated by third-party information. Rousu et al. (2004) studied negative GMO information from environmental groups using experimental auctions. Although they estimated the value of such information at US\$ 2 billion annually only for U.S. consumers, they also found that independent third-party information could dissipate most of the public good of negative GMO information. Moreover, a substantial fraction of French consumers were indifferent to GMO-free and GMO food in another study (Noussair et al. 2004).

Mandatory labeling seems like a flexible instrument when consumers' preferences are prone to change. If the willingness to pay for GMO-free food becomes lower, firms will switch to GM inputs and not care about the GM labeling. Hence, the cost saving promised by GM technology are realized.

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## Appendix

### A: Demand Functions

#### A1: With no vertical differentiation

When product  $d$  and  $f$  are both GM or both GMO free, the model is identical to the Hotelling model with demand:

$$q_d = \frac{1 - p_d + p_f}{2}, q_f = 1 - q_d = \frac{1 + p_d - p_f}{2}. \quad (9)$$

#### A2: With vertical differentiation and horizontal domination

When product  $d$  is GMO free, while product  $f$  is GM, the marginal consumers are located on the line:  $\lambda_z^* = \frac{2}{m} \left( x_{z^*} + \frac{p_d - p_f - 1}{2} \right)$ ,  $m > 0$ , dividing the unit square into two parts, reflecting the market shares of firm  $d$  and firm  $f$ , respectively. Further, the straight line has three possible different locations in the unit square. In the first case, the line cuts off the upper left corner of the unit square, and the demand for product  $d$  is just the area of the upper left part of the square:

$$q_d = 1 - \int_0^{\frac{m - p_d + p_f + 1}{2}} \frac{2}{m} \left( x + \frac{p_d - p_f - 1}{2} \right) dx - \left( 1 - \frac{m - p_d + p_f + 1}{2} \right),$$

for  $p_f + 1 \leq p_d \leq m + p_f + 1$ .

In the next case, the line with divides the unit square as in figure 1 (page 9). The line crosses the  $x$ -axis at point  $x = \frac{1 - p_d + p_f}{2}$ , and intersects the horizontal line  $\lambda = 1$  for

$x = \frac{m - p_d + p_f + 1}{2}$ . The demand for product  $d$  is the left part of the unit square:

$$q_d = 1 - \int_{\frac{p_d - p_f - 1}{2}}^{\frac{m - p_d + p_f + 1}{2}} \frac{2}{m} \left( x + \frac{p_d - p_f - 1}{2} \right) dx - \left( 1 - \frac{m - p_d + p_f + 1}{2} \right),$$

for  $p_d - p_f - 1 < 0$  and  $0 < \frac{m - p_d + p_f + 1}{2} < 1$ .

In the last case, the line divides the unit square such that just the lower-right corner is left for product  $f$ . The line crosses the  $x$ -axis at point  $x = \frac{1 - p_d + p_f}{2}$ , and it intersects the horizontal line  $\lambda = 1$  for  $x = \frac{m - p_d + p_f + 1}{2}$ ,  $\frac{m - p_d + p_f + 1}{2} \geq 1$ . The demand for product  $d$  is:

$$q_d = 1 - \int_{\frac{p_d - p_f - 1}{2}}^1 \frac{2}{m} \left( x + \frac{p_d - p_f - 1}{2} \right) dx = \frac{4m - (p_f - p_d - 1)^2}{4m},$$

for  $p_d - p_f - 1 \leq 0$  and  $\frac{m - p_d + p_f + 1}{2} \geq 1$ .

Solving the integrals, we obtain the demand function for product  $d$ :

$$q_d = \begin{cases} \frac{[m - p_d + p_f + 1]^2}{4m} & \text{for } p_f + 1 \leq p_d \leq m + p_f + 1 \\ \frac{m - 2(p_d - p_f - 1)}{4} & \text{for } m + p_f - 1 < p_d < p_f + 1 \\ \frac{4m - (p_f - p_d - 1)^2}{4m} & \text{for } p_f - 1 \leq p_d \leq m + p_f - 1 \end{cases} \quad (10)$$

Since we assume that the market is fully covered, the demand for product  $f$  is

$$q_f = 1 - q_d.$$

### A3: With vertical differentiation and vertical domination

In case of vertical domination, the slope of the straight line is smaller than 1, i.e.,  $m > 2$ . It also has three possible different locations in the unit square, but only the intermediate case differs from that of horizontal domination case. In the intermediate case, the line crosses the  $\lambda$ -axis at point  $x = 0$ , and intersects the vertical line  $x = 1$  for  $\lambda < 1$ . Hence, demand for product  $d$  is the upper part of the unit square, or the whole area above the line:

$$q_d = 1 - \int_0^1 \frac{2}{m} \left( x + \frac{p_d - p_f - 1}{2} \right) dx,$$

for  $p_f + 1 < p_d < m + p_f - 1$ .

Solving the integral, demand for product  $d$  in the vertical domination case can be written as:

$$q_d = \begin{cases} \frac{[m - p_d + p_f + 1]^2}{4m} & \text{for } m + p_f - 1 \leq p_d \leq m + p_f + 1 \\ \frac{m - p_d + p_f}{m} & \text{for } p_f + 1 < p_d < m + p_f - 1 \\ \frac{4m - (p_f - p_d - 1)^2}{4m} & \text{for } p_f - 1 \leq p_d \leq p_f + 1 \end{cases} \quad (11)$$

The demand for product  $f$  is simply  $q_f = 1 - q_d$ .

## B: NashEquilibria in the Second Stage of the Game

### B1: Both GM/Both GMO free

Demand is given in equation (9). Each  $i$  firm maximizes:

$$\pi_i = (p_i - c_i) \left( \frac{1 - p_i + p_j}{2} \right) \text{ for } i \neq j, \quad i, j = d, f,$$

and it is easy to show that, in the Bertrand-Nash price equilibrium, we obtain the following expressions for output and profit:

$$q_i(c_i, c_j) = \frac{3 - c_i + c_j}{6}, \quad \pi_i(c_i, c_j) = \frac{1}{2} \left( \frac{3 - c_i + c_j}{3} \right)^2.$$

Note that the difference in costs between the firms must not exceed 3, that is,  $(c_i - c_j) \leq 3$ .

### B2: Domestic GMO-free and foreign GM: Horizontal domination

We assume that the unique equilibrium is located on the intermediate segment of the demand functions (10). (See Neven and Thisse for a proof of NashEquilibrium uniqueness.) Assume that the domestic firm produces GMO free. Note that either we have  $c_d = c_0$  or  $c_d = c_0 + v$ . We then have that firms maximize:

$$\pi_d = (p_d - c_d) \frac{m - 2(p_d - p_f - 1)}{4},$$

$$\pi_f = (p_f - c_g) \frac{2(p_d - p_f + 1) - m}{4}.$$

The Bertrand-Nash equilibrium prices are:

$$p_d = \frac{6 + m + 4c_d + 2c_g}{6}, \quad p_f = \frac{6 - m + 4c_g + 2c_d}{6}.$$



We have to check if the equilibrium prices are consistent with the condition

$m + p_f - 1 < p_d < p_f + 1$  (See (10)). This results in the following condition:

$m \leq \min\left\{3 - c_d + c_g, \frac{3 + c_d - c_g}{2}\right\}$ . Thus, if  $m, (c_d - c_g) \in \left[0, \frac{3}{2}\right]$  the condition will always be

fulfilled. The associated NashEquilibrium outputs and profits of each firm are therefore:

$$q_d = \frac{3 + \frac{m}{2} - c_d + c_g}{6}, \Pi_d = \frac{1}{2} \left( \frac{3 + \frac{m}{2} - c_d + c_g}{3} \right)^2, \text{ and}$$

$$q_f = \frac{3 - \frac{m}{2} + c_d - c_g}{6}, \Pi_f = \frac{1}{2} \left( \frac{3 - \frac{m}{2} + c_d - c_g}{3} \right)^2.$$

### B3: Domestic GMO free and foreign GM: Vertical domination

Again, we assume that the domestic firm produces GMO free, and that the unique Nash-price equilibrium is on the intermediate segment of the demand functions (11). (See Neven and Thisse for a proof of uniqueness.) Repeat the same procedure as above, apart from replacing the demand functions with  $q_d = \frac{m - p_d + p_f}{m}$  and  $q_f = \frac{p_d - p_f}{m}$ , where

$p_f + 1 < p_d < m + p_f - 1$ , and we obtain the following equilibrium prices:

$$p_d = \frac{2m + 2c_d + c_g}{3}, p_f = \frac{m + c_d + 2c_g}{3}.$$

The set of prices constitutes a NashEquilibrium as long as

$m > \max\left\{3 - c_d + c_g, \frac{3 + c_d - c_g}{2}\right\}$ . Notice that this condition is always fulfilled when

$m > 3, \forall (c_d - c_g) \in (0, 3]$ . We then obtain the NashEquilibrium outputs and profits of each firm as follows:

$$q_d = \frac{2m - c_d + c_g}{3m}, \Pi_d = \frac{(2m - c_d + c_g)^2}{9m},$$

and if:

$$q_f = \frac{m + c_d - c_g}{3m}, \Pi_f = \frac{(m + c_d - c_g)^2}{9m}.$$

### C: NashEquilibria in the First Stage of the Game

Generally, we assume that firms produce GM free if profits are higher or equal than when producing with GM. We then look at the policy alternatives.

#### C1: Horizontal domination: Alternative A

The NashEquilibrium is “both GMO free” if:

$$\frac{1}{2} \geq \frac{1}{2} \left( \frac{3 - \frac{m}{2} + c_0 + v - c_g}{3} \right)^2,$$

which can be reduced to  $\frac{m}{2} \geq c_0 + v - c_g$ . The NashEquilibrium is “both GM” if:

$$\frac{1}{2} > \frac{1}{2} \left( \frac{3 + \frac{m}{2} - c_0 - v + c_g}{3} \right)^2,$$

which reduces to  $\frac{m}{2} < c_0 + v - c_g$ . Hence, the NashEquilibria “both GMO free” and “both GM” are mutually exclusive.

Finally, the NashEquilibrium is “only the domestic firm GMO free” if:

$$\frac{1}{2} \left( \frac{3 + \frac{m}{2} - c_0 - v + c_g}{3} \right)^2 \geq \frac{1}{2},$$

and if:

$$\frac{1}{2} \left( \frac{3 - \frac{m}{2} + c_0 + v - c_g}{3} \right)^2 > \frac{1}{2}.$$

The first condition reduces to  $\frac{m}{2} \geq c_0 + v - c_g$ , while the second condition reduces to

$\frac{m}{2} < c_0 + v - c_g$ . Hence, the conditions are mutually exclusive. Thus, we either have “both GMO free” or “both GM” with alternative A.

#### C2: Horizontal domination: Alternative B

In this case, firms have different costs. The NashEquilibrium is “both GMO free” if:

$$\frac{1}{2} \left( \frac{3+\nu}{3} \right)^2 \geq \frac{1}{2} \left( \frac{3 - \frac{m}{2} + c_0 + \nu - c_g - \tau}{3} \right)^2,$$

and if:

$$\frac{1}{2} \left( \frac{3-\nu}{3} \right)^2 \geq \frac{1}{2} \left( \frac{3 - \frac{m}{2} + c_0 - c_g}{3} \right)^2,$$

which can be reduced to  $\frac{m}{2} \geq c_0 - c_g - \tau$  and  $\frac{m}{2} \geq c_0 + \nu - c_g$  of which the latter is sufficient.

While, the NashEquilibrium is “both GM” if:

$$\frac{1}{2} \left( \frac{3-\tau}{3} \right)^2 > \frac{1}{2} \left( \frac{3 + \frac{m}{2} - c_0 + c_g}{3} \right)^2,$$

and if:

$$\frac{1}{2} \left( \frac{3+\tau}{3} \right)^2 > \frac{1}{2} \left( \frac{3 + \frac{m}{2} - c_0 - \nu + c_g + \tau}{3} \right)^2,$$

which reduces to  $\frac{m}{2} < c_0 - \tau - c_g$  and  $\frac{m}{2} < c_0 + \nu - c_g$ , of which the former is sufficient. Note that, as above, the NashEquilibria “both GMO free” and “both GM” are mutually exclusive.

Finally, the NashEquilibrium is “only the domestic firm GMO free” if:

$$\frac{1}{2} \left( \frac{3 + \frac{m}{2} - c_0 + c_g}{3} \right)^2 \geq \frac{1}{2} \left( \frac{3-\tau}{3} \right)^2,$$

and if:

$$\frac{1}{2} \left( \frac{3 - \frac{m}{2} + c_0 - c_g}{3} \right)^2 > \frac{1}{2} \left( \frac{3-\nu}{3} \right)^2.$$

The first condition reduces to  $\frac{m}{2} \geq c_0 - \tau - c_g$ , while the second condition reduces

to  $\frac{m}{2} < c_0 + \nu - c_g$ . Hence, we have “only the domestic firm GMO free” if

$$c_0 - \tau - c_g < \frac{m}{2} \leq c_0 + \nu - c_g.$$

### C3: Vertical differentiation: Alternative A

The NashEquilibrium is “both GMO free” if:

$$\frac{1}{2} \geq \frac{(m + c_0 + \nu - c_g)^2}{9m}.$$

The condition holds for small values on  $(c_0 + \nu - c_g)$  i.e., we must have

$(c_0 + \nu - c_g) \leq \sqrt{\frac{9m}{2}} - m$ . Since  $(c_0 + \nu - c_g)$  is bounded above 0, the condition cannot hold for  $m > \frac{9}{2}$ .

The outcome “both GM” is a NashEquilibrium if:

$$\frac{1}{2} > \frac{(2m - c_0 - \nu + c_g)^2}{9m}.$$

Rearranging the expression, we have  $(c_0 + \nu - c_g) > 2m - \sqrt{\frac{9m}{2}}$ . Since

$c_0 + \nu - c_g \leq 3$ , the condition cannot hold for  $m \gg 3.478$ .

The NashEquilibrium is “only the domestic firm GMO free” if:

$$\frac{(2m - c_0 - \nu + c_g)^2}{9m} \geq \frac{1}{2},$$

which holds if  $(c_0 + \nu - c_g) \leq 2m - \sqrt{\frac{9m}{2}}$ . Also, the foreign firm will produce with GM inputs

if:

$$\frac{(m + c_0 + \nu - c_g)^2}{9m} > \frac{1}{2},$$

which holds if  $(c_0 + \nu - c_g) > \sqrt{\frac{9m}{2}} - m$ .

The NashEquilibrium is “only the foreign firm GMO free” if:

$$\frac{(2m - c_0 - v + c_g)^2}{9m} \geq \frac{1}{2},$$

which holds if  $(c_0 + v - c_g) \leq 2m - \sqrt{\frac{9m}{2}}$ . In addition, the domestic firm will produce with

GM inputs if:

$$\frac{(m + c_0 + v - c_g)^2}{9m} > \frac{1}{2},$$

which holds if  $(c_0 + v - c_g) > \sqrt{\frac{9m}{2}} - m$ .

#### C4: Vertical differentiation: Alternative B

The NashEquilibrium is “both GMO free” if:

$$\frac{1}{2} \left( \frac{3+v}{3} \right)^2 \geq \frac{(m + c_0 + v - c_g)^2}{9m},$$

and if:

$$\frac{1}{2} \left( \frac{3-v}{3} \right)^2 \geq \frac{(m + c_0 - c_g)^2}{9m},$$

which can be reduced to  $c_0 + v - c_g \leq \sqrt{\frac{9m}{2}} - m + v\sqrt{\frac{m}{2}}$  and

$c_0 + v - c_g \leq \sqrt{\frac{9m}{2}} - m - v\sqrt{\frac{m-2}{2}}$ . Clearly, the latter is sufficient. Define

$l_l^v \equiv \sqrt{\frac{9m}{2}} - m - v\sqrt{\frac{m-2}{2}}$ , and the latter condition can be simplified to

$c_0 + v - c_g \leq l_l^v$ . Note that  $l_l^v$  is declining in  $m$  and  $v$ .

The outcome “both GM” is a NashEquilibrium if:

$$\frac{1}{2} \left( \frac{3-\tau}{3} \right)^2 > \frac{(2m - c_0 + c_g)^2}{9m},$$

and if:

$$\frac{1}{2} \left( \frac{3+\tau}{3} \right)^2 > \frac{(2m - c_0 - v + c_g + \tau)^2}{9m},$$

which can be reduced to  $c_0 + v - c_g > 2m - \sqrt{\frac{9m}{2}} + \tau\sqrt{\frac{m}{2}} + v$  and

$c_0 + v - c_g > 2m - \sqrt{\frac{9m}{2}} - \tau\sqrt{\frac{m}{2}} + \tau$ . Clearly, the former is sufficient since  $\frac{m}{2} > 1$ . Define  $l_h^v \equiv 2m - \sqrt{\frac{9m}{2}} + \tau\sqrt{\frac{m}{2}} + v$ , and the latter condition can be simplified to  $c_0 + v - c_g > l_h^v$ . Note that  $l_h^v$  is increasing in  $m$  and  $v$ , and further that  $\bar{l}_h > \bar{l}_l$ .

The NashEquilibrium is “only the domestic firm GMO free” if:

$$\frac{(2m - c_0 + c_g)^2}{9m} \geq \frac{1}{2} \left( \frac{3 - \tau}{3} \right)^2,$$

which holds if  $c_o - c_g \leq \bar{l}_h$ . Also, the foreign firm will produce with GM if:

$$\frac{(m + c_0 - c_g)^2}{9m} > \frac{1}{2} \left( \frac{3 - v}{3} \right)^2,$$

which holds if  $c_o - c_g \geq \bar{l}_l$ .

The NashEquilibrium is “only the foreign firm GMO free” if:

$$\frac{(2m - c_0 - v + c_g + \tau)^2}{9m} \geq \frac{1}{2} \left( \frac{3 + \tau}{3} \right)^2,$$

which holds if  $c_o - c_g \leq \bar{l}_h - 2\tau\sqrt{\frac{m}{2}} + \tau - v$ . Again, the domestic firm will produce with GM if:

$$\frac{(m + c_0 + v - c_g - \tau)^2}{9m} > \frac{1}{2} \left( \frac{3 + v}{3} \right)^2,$$

which holds if  $c_o - c_g > \bar{l}_l + 2v\sqrt{\frac{m}{2}} + \tau - v$ .

## D: Calculating Transportation Cost

### D1: Both GM/Both GMO free

Since there is only horizontal differentiation between product  $d$  and  $f$  when either both firms produce with GM inputs or they both produce GMO free, the transportation costs are the same in horizontal domination case and the vertical domination case:

$$TC = \int_0^{\frac{1-p_d+p_f}{2}} x^2 dx + \int_{\frac{1-p_d+p_f}{2}}^1 (1-x)^2 dx.$$

Solving the integrals and inserting  $p_i$  and  $p_j$ , we obtain:

$$TC = \frac{1}{12} + \left( \frac{c_i - c_j}{6} \right)^2 \quad \text{for } i \neq j, i, j = d, f.$$

Note that when both firms produce GMO free, we have  $TC = \frac{1}{12}$ .

### D2: Domestic GMO free/Foreign GM: Horizontal domination

Since, the NashEquilibrium is found on the intermediate segment of demand, the aggregate transportation cost is given by the following sum of integrals:

$$TC = \int_0^{\frac{p_f - p_d + 1}{2}} x^2 dx + \int_{\frac{p_f - p_d + 1}{2}}^{\frac{m + p_f - p_d + 1}{2}} x^2 (1 - \lambda) dx + \int_{\frac{p_f - p_d + 1}{2}}^{\frac{m + p_f - p_d + 1}{2}} (1 - x)^2 \lambda dx + \int_{\frac{m + p_f - p_d + 1}{2}}^1 (1 - x)^2 dx$$

Insert  $\lambda = \frac{2}{m} \left( x + \frac{p_d - p_f - 1}{2} \right)$  into the equation and solve the integrals:

$$TC = \frac{1}{12} + \frac{m^2}{12} + \frac{m(p_f - p_d)}{4} + \frac{(p_f - p_d)^2}{4}. \quad \text{Finally, by inserting } p_d = \frac{6 + m + 4c_d + 2c_g}{6} \text{ and } p_f = \frac{6 - m + 4c_g + 2c_d}{6} \text{ into the equation, we obtain:}$$

$$TC = \frac{1 + m^2 - m(c_d - c_g) + (c_d - c_g)^2}{12}.$$

### D3: Domestic GMO free/Foreign GM: Vertical domination

In this case, the aggregate transportation cost is given by the following sum of integrals:

$$TC = \int_0^1 x^2 (1 - \lambda) dx + \int_0^1 (1 - x)^2 \lambda dx.$$

Insert  $\lambda = \frac{2}{m} \left( x + \frac{p_d - p_f - 1}{2} \right)$ ,  $p_d = \frac{2m + 2c_d + c_g}{3}$  and  $p_f = \frac{m + c_d + 2c_g}{3}$  into the

equation and solve the integrals:

$$TC = \frac{m - 1}{3m}.$$

### E: Calculating GMO-Free Benefit

It is clear that in scenario 1 when both products are GM, none of the consumers will benefit from GMO-free quality, and  $B = 0$ . While in scenario 2, both products are GMO free and  $B = \frac{m}{2}$  (total output 1 times the average benefit  $\frac{m}{2}$ ).

In scenarios 3 and 4, since there are both GM and GMO-free food in the domestic market, only those who buy GMO-free food will benefit.

**E1: Horizontal domination case**

$$B = \int_0^{\frac{p_f - p_d + 1}{2}} \int_0^1 \lambda m d \lambda dx + \int_{\frac{p_f - p_d + 1}{2}}^{\frac{m + p_f - p_d + 1}{2}} \int_{\frac{2x + p_d - p_f - 1}{m}}^1 \lambda m d \lambda dx$$

Solve the integrals  $B = \frac{m(p_f - p_d + 1)}{4} + \frac{m^2}{6}$ . Further, by inserting  $p_d$  and  $p_f$ , we

obtain:

$$B = \frac{m^2 + 3m - m(c_d - c_g)}{12}$$

**E2: Vertical domination case**

$$B = \int_0^1 \int_{\frac{2x + p_d - p_f - 1}{m}}^1 \lambda m d \lambda dx$$

Solve the integrals  $B = \frac{m}{2} - \frac{1}{6m} - \frac{(p_f - p_d)^2}{2m}$ . Further, by inserting  $p_d$  and  $p_f$ , we

obtain:

$$B = \frac{m}{2} - \frac{1}{6m} - \frac{(m + c_d - c_g)^2}{18m}$$