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Can voluntary product-labeling replace trade bans in the case of GMOs?

Abstract:
Genetically modified (GM) food has raised both health-risk fears and environmental concerns. This has led some countries to ban the trade in such food triggering a great deal of controversy among countries. In this paper we ask under what conditions will voluntary labeling of GM-free food be at least as good as a trade ban? And, under what conditions can providing labels for GM-free food be protectionist? Our main finding is that the merits of a product labeling policy depend crucially on the way food products are differentiated. If they are poorly differentiated from the beginning, a labeling policy will probably not function as good as a trade ban does; while if they are already well differentiated, a labeling policy is likely the optimal policy for the importing country. Finally, as long as consumers' willingness to pay to avoid GM-food is high, a labeling policy is not protectionist. In fact, if products are poorly differentiated from the beginning, foreign firms will probably increase their profit even if they do not choose to label their products.

| **Discussion Papers** | comprise research papers intended for international journals or books. A preprint of a Discussion Paper may be longer and more elaborate than a standard journal article, as it may include intermediate calculations and background material etc. |

1 Introduction

Food made with genetically modified (GM) inputs has raised both health-risk fears and environmental concerns among the public. This has led some countries to ban the trade in such food, which again has triggered a great deal of controversy among countries. After a 4-year moratorium on approving import of new GM food and animal feed, the European Union (EU) is considering a move to a mandatory labeling scheme for GM food products.[1]. However, this has only partly solved the trade controversies as US exporters to the EU claim that a compulsory scheme will give their food products a negative connotation. Further, although there is no measure in the GATT that directly addresses the use of product labeling based on production methods, WTO has been sceptical to mandatory product labeling schemes in general on the grounds that they may be used as hidden protectionism.

The extent to which GM inputs pose health risks and/or environmental risks is controversial see e.g. the EU GMO Compass[12]. We therefore treat such potential risks as subjective beliefs held by consumers and governments. Further, for our analytical purpose, we separate the potential risks of GM food into: a) potential health effects restricted to the consumer who buys and eats the food, and b) potential environmental effects from the production of GM inputs, that is, less ecosystem variation, general biodiversity loss, less resilient world food production, etc. To the extent that the consumer believes these risks to be real, we assume that she will be willing to pay a premium for GM-free food.

A sizeable economics literature on the willingness to pay for ecologically labelled products has been developed. Lusk and Fox [17] find a widespread preference for mandatory labeling of beef produced with growth hormones and of beef fed genetically modified corn and a willingness to pay higher prices for beef to obtain such information. Almost all tuna fish sold in the US now has a "dolphin safe" label. In order to obtain the label, the number of dolphins killed accidentally during a tuna fish catch has to be below a certain limit set by the US government. In an empirical study Teisl, Roe and Hicks [29] found that the label had led to a significant increase in total tuna fish sales. There is also a study from Denmark on shop purchases data by Bjørner et al. [4]. They found that the Nordic Swan eco-label significantly increased the marginal willingness to pay for environmentally approved detergents and toilet paper.

In this paper, we consider the following research questions: Under what conditions, that is, assumptions about consumers preferences, production technology etc., will a *voluntary* product labeling policy covering the use of GM inputs in food products be at least as good as a trade ban with respect to a domestic welfare measure? And, under what conditions can public sponsoring of a voluntary labeling scheme for food that does not include GM

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[1]The total ban of European Union on GM food and animal feed was in effect from 1999 to 2004[12].

inputs be characterized as protectionist?

Our point of departure is a model of a representative market for some kind of food product. 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 have therefore chosen to model our representative food market as a Bertrand duopoly with horizontal differentiation. This implies that the producers make positive profits, and there is scope for protectionism i.e. setting policy such that profit is shifted from the foreign producer to the domestic producer.

The content of GM inputs in food can neither be observed before purchase nor experienced after purchase, and hence, this property of the product is a so called *credence attribute*. Firms may find it difficult to supply credence goods to the extent that consumers discredit firms' product claims. By introducing a product label scheme the government makes it possible for firms to commit to produce without using GM inputs. As we later argue, if producers choose differently with respect to the content of GM inputs in their food products, products may become vertically differentiated in addition to horizontally differentiated. Hence, we include both dimensions of differentiation in our model.

There exists a well developed strand of theoretical literature analyzing consumers' demand for environmental quality in models of pure vertical differentiation, see for instance Bansal and Gangopadhyay [3] and Amacher et al. [1].[2] Since environmental performance is the only dimension of which product differentiation occurs in this literature, firms must implicitly have been making zero profit at the time the environmental differentiation was introduced. Consequently, an analysis of protectionism connected to the introduction of product labelling scheme would be trivial, that is, firms could only increase their profits. Instead, as already mentioned, we base our analysis on a model with both horizontal and vertical differentiation. Neven and Thisse [22] were the first to analyze such a model, and we build on the application of Neven and Thisse's work found in Greaker [11].

We assume that the legislators can choose among the following policy alternatives: I) Prohibit domestic growing and utilization of GM inputs, and impose a trade ban on import of GM foods or, II) Prohibit domestic growing and utilization of GM inputs, but allow import of GM foods or, III) Admit domestic growing and utilization of GM inputs, and allow import, but offer a public sponsored, voluntary GM-free labeling scheme or, IV) Restrain from regulation, and admit growing of GM inputs, production and import of GM food.[3]

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[2] As far as we know, Conrad [5] is the only contribution that provides an analysis of consumers' demand for environmental quality in a pure horizontal differentiation model.

[3] Note that we are not analyzing a mandatory GM-label. In our model such a label would have precisely the same effect as a voluntary GM-free label. In both cases the consumers are able to identify the products. Further, the market outcome is the same independent of whether the producers must pay to avoid a label with a *negative* effect, or whether they

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While imposing a ban on both production and import on GM foods will likely have the consequence of provoking a trade dispute, a pure domestic ban or a voluntary GM-free label is more likely to be acceptable to the existing trade regimes. At least this should hold as long as the use of these instruments, in particular the label, can be shown not to be protectionist. To be able to discuss protectionism, we use a definition taken from Fischer and Serra [7]. They define a domestic policy measure to be protectionist when the use of the instrument in question, for instance an environmental tax, exceeds what a planner would impose if all producers were local. A typical example could be when the loss in foreign profit overcompensates the domestic welfare gain from the use of the measure.

First of all, our results show that in many cases it is better for a government to introduce a GM-free label, and get either both firms or just the domestic firm to adopt the label, than to enforce either a trade ban or a domestic ban. However, the merits of a product labeling policy depend crucially on the way food products are differentiated. If they are poorly differentiated from the beginning, the labeling policy will probably not function as good as a trade ban; while if they are already well differentiated, a labeling policy is likely the optimal option.

With respect to the issue of protectionism, there is scope for shifting profit from foreign firms to domestic firms by choosing the right domestic environmental policy instrument. Among others, compared to a trade ban, we show that a labeling policy is always less or equally harmful to the foreign firm. Further, provided that the private willingness to pay to avoid GM food is sufficiently high, a labeling policy is never protectionist.

2   Potential benefits and damages of GMOs

Genetic Modification is a biological technique which involves artificial transfer of functional genes across species boundaries to produce novel organisms, so called GMOs. By extracting a particular gene from a cell of one species and inserting it into the genetic code of another species, a particular desirable characteristic is hoped to be introduced. This technique has been widely applied in food production[4].

Studies document that adoption of GM on crops results in higher field yield and substantial reduction of the use of chemical sprays, at least in the short run[5]. The production cost is lowered, and the price of food may hence be reduced. Advocates for GMOs claim that local habitats and ecosystem are also protected, and biodiversity of insects appears to have been enhanced via

must pay to obtain a label with a *positive* effect.

[4] GM technology is capable of modifying a large number of traits: pest resistance, ripening time, starch content, sterility, fungus resistance, fat content, bacteria-virus resistance, herbicide resistance, nutrition content, taste, antibiotic resistance, flowering, etc.

[5] Investigations in Mexico show that the use of Bt cotton by small and middle scale farmers lowered the pesticide cost by more than US$100/ha. Net profit advantage amounted to nearly US$600/ha [15]. In the US, adoption of GM crops resulted in pesticide use reduction of 45.6 million pounds in 2001[10].

less poison exposure [27]. In this paper, we simply capture the potential gain from GMOs by the cost advantage of GM ingredients.

However, as a growing number of products derived from GM crops have been introduced into the market and our diets, questions about their potential risks to human health and the environment have been raised.[6]

2.1 GMOs' potential health effects

Whether food products manufactured from GM inputs have health effects is debated, and as far as we understand, there is no consensus on any of the potential health effects. According to the proponents of the view that GM food have health effects, the alteration of DNA can interfere with the initial stable DNA system within the same cells, and cause changes which are uncertain and unpredictable. For instance, some cells may produce toxic and allergic substances that need long term to emerge. Although many testing procedures have been implemented, it does not necessarily assure that the approved products are really safe. In 1989, 37 Americans died after taking in *L-tryptophan*-contained food additive which is made from GM bacteria, despite the fact that this type of food additives had been tested over 15 years [18], [25].

Another concern related to GM food is that an allergen, a protein that causes an allergic reaction, could be accidentally introduced into new food products [8], [9], [26]. Soybeans modified with Brazil nut genes, for instance, have been found to express Brazil-nut proteins of the sort that might trigger allergic reaction [23].

Further, some GM crops contain genes for a trait called antibiotic resistance. Concerns have been raised that these marker genes could move from GM crop to microorganisms in the human intestinal system, and lead to an increase in antibiotic resistance. [14], [20].

In addition to the health risks mentioned above, it seems clear that many consumers have a preference for so-called *natural food*. The growing markets for ecological food in both Europe and the US are an evidence of that. Consumers preferring *natural food* will tend to look at the use of GM inputs as unnatural or artificial, and hence, will likely be willing to pay to avoid such inputs.

2.2 GMOs' potential environmental damages

Whether or not GMOs involve potential environmental risks is also controversial. A major environmental concern associated with GMOs is their potential to create new weeds resistant to herbicides, so-called "superweeds", see Warwick [31].. This can happen if genes "flow" from GMO crops to weeds, for instance, glyphosate tolerance is now known in rigid ryegrass, a pernicious

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[6]Economic risks of GMOs have been widely cited too. The so-called GM companies have introduced a number of anti-competition business practices, such as "tie-in contracts", "rental contracts", and "terminator seeds"[13]. Thus, there is a fear that the world's food supply will be finally controlled in a few large firms' hands.

weed [6]. If herbicide tolerant weeds spread, there is concern that more toxic herbicides may be required, which again will affect the environment negatively.

Another concern is that crops genetically modified to repel pests might spur the evolution of "superbugs". Over 500 species of insects have developed resistance to insecticides [21]. As a result, stronger and larger amount of toxins have to be sprayed, triggering a potential vicious circle.

Adoption of GMO crops may also reduce the genetic diversity in important native food crops. If pollen from GMO crops blow or spill into fields of organic plants and fertilize them, many fear that GMO crops may ultimately compete out the local land races with their unique genetic variation, see for instance Squire[28]. In some places, say, Mexico, home of thousands of wild relatives to cultivated plants, the gene flow could possibly cause serious repercussions as for instance irreversible loss of genetic material, and consequently, a less resilient world food production in the long term, see for example Aslaksen et al[2].

GM crops also have potential to harm other wild habitants in the fields, from microbes to songbirds. In May 1999, it was reported that pollen from Bt insect-resistant corn had a negative effect on Monarch butterfly larvae [16]. This report raised public worries that GMOs could poison the wild lives and endanger the biological diversities, putting local landscape and ecosystem under threat. Although later studies has questioned the report[24], many still seem to believe that there is some chance that GMOs could have such effects, see for example Aslaksen et al[2].

In order to model the potential environmental damages from the use of GM inputs we make the following assumptions: I) The growing of GM crops may have global environmental impacts like irreversible loss of genetic material independent of where the GM crops are located, II) The growing of GM crops may also have local environmental impacts, however, of course only to the extent that GM crops are grown in the country in question.

2.3 Modelling consumers willingness to pay for GM-free food

We assume that consumers are concerned about the potential effects of GM food on human health as well as the environment. Hence, given that all other conditions including the price are the same, consumers will in general prefer GM-free food. However, the extent to which a particular consumer is willing to pay a premium for GM free food depends on that consumer's personal belief about the potential risks of GM food. In other words, consumers evaluate food quality according to their own judgement. Consumers' sovereignty leads us to accept their subjective beliefs as they are.

We write an arbitrary consumer's willingness to pay to avoid food products with GM inputs: λm, where λ is uniformly distributed on $[0,1]$. While λ reflects consumers' subjective beliefs about the seriousness of the potential risks in relative terms, m is a parameter measuring the general strength of the preferences for GM-free food in the population.

3 The model

The model consists of a three-stage game between a domestic government, a representative domestic food manufacturer and a representative foreign food manufacturer exporting to a domestic market for some type of packaged food. The production process of the representative firms may involve the use of GM inputs. At Stage 1, the domestic government chooses policy towards the use of GM ingredients. At Stage 2, the domestic representative firm d and the foreign representative firm f simultaneously choose whether to use GM inputs in their production of food products. Finally, in Stage 3, the two firms compete in prices on the domestic market. While there is perfect information among the domestic government and the firms, domestic consumers cannot know or observe the content of GM ingredients in the food products.

3.1 Firms

We assume that the two food producers utilize inputs that are grown locally. Further, there are two types of inputs: GM and GM-free. We simply call food made from one or more GM ingredients "GM food", and food made from *all* GM-free ingredients "GM-free food". Due to the desirable properties of GM crops, such as increasing yields and reducing chemical sprays, GM ingredients are cheaper than the corresponding GM-free ingredient.

Let c_o denote the unit cost of GM-free input for both firms. Let c_g represent the cost of GM input for firm f, while $\frac{c_g}{\alpha}$ represents the cost for firm d, where $\alpha \in \langle 0, 1]$, is a parameter reflecting potential cost asymmetries between the firms with respect to utilizing GM inputs. In countries in which GMOs historically have not encountered much resistance, and where there is a larger scale of production, like the US for instance, the cost of GM input may be cheaper than in countries that have little experience with GM inputs. We also assume $\frac{c_g}{\alpha} < c_o$.

The unit costs of each firm is then:

$$c_d = \begin{cases} c_o \text{ if producing GM-free food} \\ \frac{c_g}{\alpha} \text{ if producing GM food} \end{cases}, \tag{1}$$

$$c_f = \begin{cases} c_o \text{ if producing GM-free food} \\ c_g \text{ if producing GM food} \end{cases}.$$

The profits of the firms are given by:

$$\pi_i \left(p_d, p_f \right) = \left(p_i - c_i \right) q_i \left(p_d, p_f \right), \; i = d, f \tag{2}$$

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

Lastly, we assume 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.

3.2 Consumers

Like in the Hotelling model of horizontal differentiation (see e.g. Tirole [30], page 279), we assume 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 normalize 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. Each consumer's subjective belief about the potential damages of GM inputs i.e. λ is measured along the vertical axis of the unit square, while 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.

We assume 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. 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 assume this to be given by history, and that the horizontal location cannot be changed without incurring high fixed costs.[7]

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 $[0,x]$ along the bottom line in the unit square. The gross utility from consuming one unit of the domestic product located at $(0,0)$ of a consumer located at x is then:

$$u_x^d = \Gamma - \beta x^2 + \lambda_x m \tag{3}$$

where the term βx^2 is the loss in utility of not being able to get a product located at x i.e. a product with a brand proliferation exactly equal to the most preferred product of the consumer at x. The parameter β then expresses the general strength of consumers' taste in the horizontal dimension such as preferences for food flavour or food packaging design, while the location x measures how far the particular consumer at x is from the domestic product at $(0,0)$. The parameter β is often coined the *transportation cost* parameter, and the term βx^2 the *transport costs*.

The term $\lambda_x m$ is the benefit λm received by the consumer located at x from consuming a GM-free food product. In particular, λ_x is the subjective belief held by the consumer at x about the disadvantages of GM inputs, and m is a parameter measuring the general strength of the preferences for GM-free food as already mentioned. Note that the benefit $\lambda_x m$ is only recieved if the consumer can be sure that the product is really GM-free, which is the case if a GM-free label is observed on the product or if food containing GM inputs is banned by the government.

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[7]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, see Tirole p. 281 [30]. We assume quadratic transportation costs, see below.

The parameter Γ is a constant utility term, which all consumer derives from consuming one unit of food. It is measured ex transportcosts, and for a product containing GM-inputs.

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

$$u_x^f = \Gamma - \beta(1-x)^2 + \lambda_x m \tag{4}$$

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 call the consumer who is indifferent between buying product d and f *the marginal consumer*, and denote the location of the marginal consumer by x^*. The location of the marginal consumer can be found by equalizing the surplus from buying product d and from product f. When products are equal with respect to GM content, we obtain for the location of the marginal consumer:

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

i.e. the location x^* is independent of λ, and hence the unit square is dived by a vertical line at x^*, which for $p_d = p_f$ divides the unit square into two identical parts of size $\frac{1}{2}$. All consumers to the left of the line given by (5) buy the domestic product, and all consumers to the right of the line given by (5) buy the foreign product. The division of the market is *independent* of λ since both products are either GM-free or GM containing.

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

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

The sign in front of $\frac{m}{2\beta}$ is positive when product d is GM-free and product f is GM, and negative if *vice versa*. Depending on the value of $\frac{m}{2\beta}$, the unit square can be divided in two fundamentally different ways. In Figure 1 we have drawn the line dividing the market given by (6) in the two cases of *horizontal domination* and *vertical domination* as explained below:

Figure 1. The division of the market.
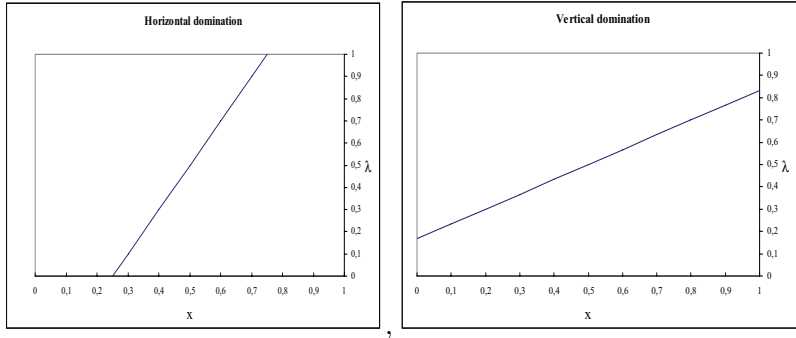
In Figure 1 the domestic firm produces GM-free and the foreign firm produces with GM inputs. All the consumers to the left of the line defined by (6) buy the domestic product, whereas all the consumers to the right of the line buy the foreign product. Note that we assume $p_d > p_f$, such that a consumer located at $x = 0.5$ will only buy from firm d if her $\lambda \gtrless 0.5$.

When products are well differentiated from the beginning i.e. β 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", while when products are poorly differentiated from the beginning 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 a consumer placed at $(1,0)$ may buy from the domestic firm at $(0,0)$ provided that her λ is above ≈ 0.84 (the intersection of the line (6) with the λ-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 independent of their λ. That is, all consumer to the left of the intersection between the bottom line ($\lambda = 0$) and the dividing line (6) will buy the domestic product independent of their λ, and all consumers to the right of the intersection between the top line ($\lambda = 1$) and the dividing line (6) will buy the foreign product independent of their λ. This difference turns out to be important when calculating the optimal GM-free label adoption strategies of the firms.

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

3.3   The domestic government

The government maximizes social welfare by choosing a policy from the alternatives: I) Forbid domestic growing and utilization of GM inputs, and impose a trade ban on import of GM foods or, II) Forbid domestic growing and utilization of GM inputs, but allow import of GM foods or, III) Admit

domestic growing and utilization of GM inputs, and allow import, but offer a public sponsored, voluntary GM-free labeling scheme or, IV) Restrain from regulation, and admit growing of GM inputs, production and import of GM food. Social welfare consists of consumer surplus, producer surplus and the state of both the local and the global environment.

Let CS be the aggregate consumers' 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 her most preferred product in the horizontal dimension. Further, B is the aggregate benefit from consuming GM-free food. (See Appendix D and E for a complete derivation of both TC and B).

Clearly, what happens in one particular packaged food market, will have very little effect on aggregate demand for GM inputs and hence, likely also on the environment. However, since what is happening in our market is taken to be representative for all other domestic packaged food markets, domestic policy towards GM inputs could have a significant effect on both local and global environmental damages, in particular, if the total size of the domestic food market is large (like the EU market). To capture GMOs' effects on the environment, we introduce $\widetilde{D}$ as a convex environmental damage function with the size of area used for GM crops and the spatial distribution of GM crops as its main arguments. As already mentioned, there is great controversy over GMOs' impact to the environment, and hence, we consider $\widetilde{D}$ as the subjective belief of the domestic government about the potential environmental damages. Further, we assume that a higher output of GM food will *ceteris paribus* lead to a higher use of GM inputs, which will *ceteris paribus* lead to a larger area used for GM crops. Let then $\tilde{D}$ take the following forms:

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\widetilde{D} = \begin{cases} D^G(q_d + q_f; Q_w) + D^L(q_d) & \text{if both } d \text{ and } f \text{ are GM} \\ D^G(q_d; Q_w) + D^L(q_d) & \text{if only } d \text{ are GM} \\ D^G(q_f; Q_w) & \text{if only } f \text{ are GM} \\ D^G(0; Q_w) & \text{if both } d \text{ and } f \text{ are GM-free} \end{cases} \tag{7}
$$

where D^G is reflecting the domestic country's stake in the potential global environmental damages, and D^L is reflecting the potential local environmental damages i.e. damages confined to the domestic country such as the evolution of local "superbugs" and/or "superweeds". The arguments in the environmental damage functions are the outputs of GM food for which we have $\partial D^G / \partial (q_d + q_f) > 0$ and $\partial D^L / \partial q_d > 0$.

The symbol Q_w denotes the world production of GM food taking place outside the domestic country, though, not including the foreign production that goes for export to the domestic country. We treat Q_w as exogenously given, and hence, we leave it out in the following sections. Clearly, we can have $D^G(q_d + q_f; Q_w) \approx D^G(q_d; Q_w) \approx D^G(q_f; Q_w) \approx D^G(0; Q_w)$, if the effect of domestic policy on the global use of GM inputs are minimal i.e. $(q_d + q_f)/Q_w \approx 0$.

The domestic welfare function is then:

$$W_d = \Gamma - TC + B - p_d q_d - p_f q_f + \pi_d - \widetilde{D}, \tag{8}$$

where the first five terms are consumers surplus, the sixth term is the profit of the domestic firm and the last term is the level of environmental damage. Notice that apart from the constant Γ, all the terms in (8) will depend on the policy choice of the domestic government.

We assume that the foreign country is only concerned about the benefit from the one-way trade, i.e., the profit of its firm f from exporting to the domestic country:

$$W_f = \pi_f. \tag{9}$$

It follows that the subjective belief of the foreign government must be $D^L(q_f) \approx 0$ and $D^G(\cdot; Q_w) = 0$.

In the following we solve the model for the two major cases, that is, the case when products historically are well differentiated, and the case when they historically are poorly differentiated.

4 Products are well differentiated *ex ante*

When consumers make their purchase decisions, if they put more weight on products' horizontal aspects represented by the value on β relative to the vertical aspect represented by the value on m, we say that products are well differentiated *ex ante* or as Neven and Thisse [22] coin it, we have *horizontally dominated* demand. On example could be breakfast cereals made from GM or not GM corn.

We consider the horizontal domination case here, and deal with the vertical domination case in the next section. Since β is fixed to unity, m cannot be too high. Let $0 \leq m \leq \frac{3}{2}$, which ensures that we have horizontal domination, and let $0 < (c_o - c_g) \leq \frac{3}{2}$ which ensures that the analytical solution to the game is tractable (see Appendix B).

4.1 The third-stage game: The Bertrand Equilibrium

There are four possible market outcomes in our model: Scenario 1 where both firms produce GM food, Scenario 2 where both firms produce GM-free food, Scenario 3 where firm d produces GM-free food while firm f produces GM food, and Scenario 4 where firm d produces GM food while firm f produces GM-free food.

In Scenario 1 and 2 there is only horizontal differentiation in product d and f, and the model is identical to the Hotelling model (see e.g. Tirole [30], page 279). While in Scenario 1 firms have asymmetric unit cost of GM input, in Scenario 2 firms are symmetric. Further, in Scenario 1 firm f has a relative cost advantage, and consequently a higher market share and a lower price. In Scenario 2 firms set the same price and share the market equally.

In scenario 3 and 4, where product d and f are differentiated in both horizontal and vertical dimension, demand functions $q_i(p_d, p_f), i = d, f$ are

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composed by three segments, and the unique Bertrand-Nash equilibrium will be found in the intermediate segment (see Appendix A for the derivation of demand functions). The results of these two scenarios are just mirror reflections of each other, except that firm d's unit GM input cost is $\frac{c_g}{\alpha}$ rather than c_g. The results of the third-stage game are summarized in the following Table 1 (see Appendix B for the derivation).

Table 1: Market equilibrium profit

Market outcome	Domestic firm profit	Foreign firm profit
Scenario 1 GM only	$\frac{1}{2}\left(\frac{3-\frac{c_g}{\alpha}+c_g}{3}\right)^2$	$\frac{1}{2}\left(\frac{3+\frac{c_g}{\alpha}-c_g}{3}\right)^2$
Scenario 2 GM-free only	$\frac{1}{2}$	$\frac{1}{2}$
Scenario 3 Firm d GM-free Firm f GM	$\frac{1}{2}\left(\frac{3+\frac{m}{2}-c_o+c_g}{3}\right)^2$	$\frac{1}{2}\left(\frac{3-\frac{m}{2}+c_o-c_g}{3}\right)^2$
Scenario 4 Firm d GM Firm f GM-free	$\frac{1}{2}\left(\frac{3-\frac{m}{2}+c_o-\frac{c_g}{\alpha}}{3}\right)^2$	$\frac{1}{2}\left(\frac{3+\frac{m}{2}-c_o+\frac{c_g}{\alpha}}{3}\right)^2$

4.2 The second-stage game: GM or GM-free

Both firms have two pure strategies in their strategy spaces: to produce GM-free food and to produce GM food, and the payoffs are simply the associated profits. We assume that firms cannot commit to produce GM-free without some kind of guarantee from the government that food products really are GM-free. Thus, if the government restrains from regulation (Policy alternative IV), the representative food market we are looking at will resemble a typical example of adverse selection. Due to the cost advantage of GM food, GM-free food will be crowed out of the market, and we will end up with a market for "lemons", that is, a market with GM food only.[8]

On the other hand, when the domestic government imposes a ban on both domestic production and import of GM food, the firms can only produce and sell GM-free food (Policy alternative I). Consequently, there will only be more costly GM-free food in the domestic market, and consumers with a low valuation of the GM-free quality will likely loose.

Policy alternative II), that is, "forbid domestic growing and utilization of GM inputs, but allow import of GM foods", will also lead to one particular market outcome. The domestic firm will have to produce GM-free food, while the foreign firm cannot do better than producing GM food. By assumption,

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[8]We discuss this assumption further in Section 6.

there is no way for the foreign firm to commit to produce GM-free food even if that is profitable.

Finally, under a GM-free labeling policy (Policy alternative III), the resulting equilibrium market outcome is not this straightforward. Depending on the relative magnitude of $\frac{m}{2}$, $(c_o - c_g)$, $(c_o - \frac{c_g}{\alpha})$, we can have three types of unique Nash equilibriums (see Appendix C.1 for more details). Note that the term $\frac{m}{2}$ represents the average benefit of GM-free food, the term $(c_o - c_g)$ gives the cost advantage for firm f between GM-free input and GM input, while $(c_o - \frac{c_g}{\alpha})$ gives the cost advantage for firm d between GM-free input and GM input.

Table 2: Second-stage Nash-equlibriums with GM-free labeling

Benefit from GM-free	Market outcome
$\frac{m}{2} \geq (c_o - c_g)$	Both GM-free
$\left(c_o - \frac{c_g}{\alpha}\right) \leq \frac{m}{2} < (c_o - c_g)$	Firm d GM-free Firm f GM
$\frac{m}{2} < (c_o - \frac{c_g}{\alpha})$	Both GM

Note that no matter which policy alternative is chosen, there are only three possible market outcomes in the domestic market, i.e. Scenario 1, 2 and 3. Note also that if the average willingness to pay to avoid GM-inputs $\frac{m}{2}$ is high enough, both firms will choose to produce GM-free. 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 $\frac{m}{2}$ is high, you should produce GM-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. When products already are well differentiated, it is the *demand effect* that dominates. However, when products are poorly differentiated, we will see in the next section that the *strategic effect* dominates (see also Tirole[30], p. 280-281).

When considering whether a GM-free label can be characterized as protectionism, we need to compare the profit of the foreign firm for the chosen policy with the profit of the foreign firm with the other policies. This gives rise to the following proposition:

Proposition 1 *The profit of the foreign firm is always higher with no regulation than with a trade ban. Further, the profit of the foreign firm is either equal to or higher with a GM-free labeling scheme than with a trade ban.*

A trade ban results in Scenario 2 (see Table 1), while no regulation results in Scenario 1 above (see Table 1). It is then easy to see that the first part of the proposition holds. Moreover, the second part must also hold since given that the domestic firm has chosen the eco-label, the foreign firm can choose

between adopting the GM-free label, which will result in the same outcome as a trade ban, or not adopting the GM-free label, which in this case must lead to a higher profit than in the both GM-free scenario.

4.3 The first-stage game: Comparing welfare levels

While the outcomes of the policies total band and no regulation are given, the outcome of a labeling policy depends on the parameters m, c_g and c_o. In order to find the optimal policy the government must compare the levels of welfare under the different policies and the respective attainable scenarios.

Let $\overline{\Gamma} = \Gamma - \frac{7}{12}$, and normalize $D^G(0)$ to zero. Welfare under the different policies are then given in the table below:

Table 3: Domestic welfare

No regulation and GM-free labeling if $\frac{m}{2} < c_o - \frac{c_g}{\alpha}$	$\overline{\Gamma} + \frac{\left(\frac{c_g}{\alpha} - c_g\right)^2}{12} - \left(\frac{5}{6}\frac{c_g}{\alpha} + \frac{c_g}{6}\right)$ $-D^G(1) - D^L(q_d)$
Total ban and GM-free labeling if $\frac{m}{2} \geq c_o - c_g$	$\overline{\Gamma} + \frac{m}{2} - c_o$
Domestic ban and GM-free labeling if $\left(c_o - \frac{c_g}{\alpha}\right) \leq \frac{m}{2} < (c_o - c_g)$	$\overline{\Gamma} + \frac{5m}{12} - \left(\frac{5}{6}c_o + \frac{c_g}{6}\right)$ $-\frac{m^2 + 2m(c_o - c_g) - 2(c_o - c_g)^2}{72} - D^G(q_f)$

Transport costs and potential environmental costs are minimized and the aggregate benefits from GM-free products are maximized when both products are GM-free. Transport costs are minimized since in this scenario, products are symmetric with respect to costs and quality, and hence, the unit square is divided exactly at the middle by a vertical line. Thus, all consumers buy the product that is closest to them in the taste dimension. On the other hand, production costs are higher in this scenario, and lowest in the only GM products case, for instance, looking at the third term in each expression for welfare, we have $c_o > \left(\frac{5}{6}c_o + \frac{c_g}{6}\right) > \left(\frac{5}{6}\frac{c_g}{\alpha} + \frac{c_g}{6}\right)$.

The optimal policy of the domestic government will depend on the relative magnitude of $\frac{m}{2}$, $(c_o - c_g)$, $\left(\frac{c_g}{\alpha} - c_g\right)$, and $\tilde{D}$. Firstly, we present our results when $D^L(\cdot) = 0$, and $D^G(1) \approx D^G(q_f) \approx 0$. In other words, we are in a situation in which domestic policy has no effect on the level of environmental damages.

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4.4 Optimal policy

4.4.1 Without environmental costs

As a tie-breaking rule we assume that the domestic government prefers a GM-free labeling scheme to a total ban when welfare for these two policy options are equal, and a GM-free labeling scheme to a domestic ban when welfare for those two policy options are equal. Moreover, we assume that the domestic government prefers no regulation to a GM-free labeling scheme when welfare for these two policy options are equal. We then have the following propositions:

Proposition 2 *When m is high, that is $\frac{m}{2} \geq (c_o - c_g)$, a GM-free labeling scheme is the preferred policy, and such policy is not protectionist.*

Proof. When $\frac{m}{2} \geq (c_o - c_g)$, a GM-free labeling scheme gives the same outcome as a total ban: GM-free only.

Compare no regulation with a GM-free labeling scheme: Let $\frac{m}{2} = (c_o - c_g)$, and we have:

$\left(\overline{\Gamma} + \frac{m}{2} - c_o\right) - \left[\overline{\Gamma} - \frac{10\frac{c_g}{\alpha} + 2c_g - \left(\frac{c_g}{\alpha} - c_g\right)^2}{12}\right] = \frac{5}{6}\left(\frac{c_g}{\alpha} - c_g\right) - \frac{1}{12}\left(\frac{c_g}{\alpha} - c_g\right)^2 > 0$,

since $\left(\frac{c_g}{\alpha} - c_g\right) \in \langle 0, 1]$ when $\frac{c_g}{\alpha} < c_o$. (In fact it hold for $\forall(\frac{c_g}{\alpha} - c_g) < 10$).

Compare a domestic ban with a GM-free labeling scheme: Let $\frac{m}{2} = (c_o - c_g)$, and we have:

$\left(\overline{\Gamma} + \frac{m}{2} - c_o\right) - \left[\overline{\Gamma} + \frac{5m}{12} - \left(\frac{5}{6}c_o + \frac{c_g}{6}\right) - \frac{m^2 + 2m(c_o - c_g) - 2(c_o - c_g)^2}{72}\right] = \frac{(c_o - c_g)^2}{12} > 0$.

In order for the chosen policy not to be protectionist, we must have: $\frac{5}{6}\left(\frac{c_g}{\alpha} - c_g\right) - \frac{1}{12}\left(\frac{c_g}{\alpha} - c_g\right)^2 \geq \frac{1}{2}\left(\frac{3 + \frac{c_g}{\alpha} - c_g}{3}\right)^2 - \frac{1}{2}$ i.e. the gain in welfare for the domestic country has to be greater than the loss in profit for the foreign firm. By rearranging, the condition can be written as: $\left(\frac{c_g}{\alpha} - c_g\right) \geq \frac{5}{18}\left(\frac{c_g}{\alpha} - c_g\right)^2$, which has to be true (In fact it hold for $\forall(\frac{c_g}{\alpha} - c_g) < \frac{18}{5}$). Further, we know that if $\frac{m}{2} \geq (c_o - c_g)$, the foreign firm will adopt the GM-free label. Hence, its profit with a domestic ban must be less than with a GM-free labeling scheme. ∎

Clearly, as long as consumers value GM-free products highly, and no regulation will lead to only GM products, some kind of regulation is desirable. Further, in order to avoid a potential trade conflict, the government provides an GM-free label, which leads to exactly the same level of welfare as a trade ban (disregarding the cost of a potential trade conflict).

Proposition 3 *When m is low, that is $\frac{m}{2} < \left(c_o - \frac{c_g}{\alpha}\right)$, no regulation is the preferred policy.*

Proof. When $\frac{m}{2} < \left(c_o - \frac{c_g}{\alpha}\right)$, a GM-free labeling scheme gives the same outcome as no regulation: GM only.

Compare no regulation with a total ban: Let $\frac{m}{2} = (c_o - \frac{c_g}{\alpha})$ and observe:
$$\left[\overline{\Gamma} - \frac{10\frac{c_g}{\alpha} + 2c_g - \left(\frac{c_g}{\alpha} - c_g\right)^2}{12}\right] - \left(\overline{\Gamma} + \frac{m}{2} - c_o\right) = \frac{1}{6}\left(\frac{c_g}{\alpha} - c_g\right) + \frac{1}{12}\left(\frac{c_g}{\alpha} - c_g\right)^2 > 0.$$

Compare no regulation with a domestic ban: Let $\frac{m}{2} = (c_o - \frac{c_g}{\alpha})$ and observe: $\left[\overline{\Gamma} - \frac{10\frac{c_g}{\alpha} + 2c_g - \left(\frac{c_g}{\alpha} - c_g\right)^2}{12}\right] - \left[\overline{\Gamma} + \frac{5m}{12} - \left(\frac{5}{6}c_o + \frac{c_g}{6}\right) - \frac{m^2 + 2m(c_o - c_g) - 2(c_o - c_g)^2}{72}\right] = \frac{3(c_g/\alpha - c_g)^2 + 2(c_o - c_g/\alpha)^2 + 2(c_o - c_g/\alpha)(c_o - c_g) - (c_o - c_g)^2}{36} > 0$ for $\alpha \in \left\langle\frac{c_g}{c_o}, 1\right]$. ∎

Again, intuitively, as long as consumers have a low valuation of GM-free products and the environmental damage of GMOs is perceived to be zero by both governments, there is no problem that no regulation will lead to only GM products. Note that a GM-free labeling scheme would have led to the same level of welfare as no regulation since no firm would have chosen to adopt the eco-label.

Proposition 4 *When m is intermediate, that is, $\left(c_o - \frac{c_g}{\alpha}\right) \leq \frac{m}{2} < (c_o - c_g)$, a GM–free labeling scheme may dominate the other two policies, but no general ranking is possible. It is also impossible to say* a priori *whether a labeling policy is protectionist.*

When m is intermediate, a GM–free labeling scheme gives the same outcome as a domestic ban, that is, only the domestic firm produces GM-free. Hence, we don't have to consider a domestic ban. With respect to the rest of the proposition we use a numerical example to illustrate that any of the three other policy choices may be the optimal policy. Let the cost advantage of using GM inputs $c_o - c_g$ be equal to $1.2 - 1.0 = 0.2$.

Table 4: Welfare - no environmental costs

Conditions	Trade ban	No regulation	GM-free label
$\frac{m}{2} = 0.19$, $c_o - \frac{c_g}{\alpha} = 0.099$	*0.990*	0.917	0.989
$\frac{m}{2} = 0.10$, $c_o - \frac{c_g}{\alpha} = 0.099$	0.900	*0,917*	0,916
$\frac{m}{2} = 0.10$, $c_o - \frac{c_g}{\alpha} = 0.079$	0.900	0.900	*0.916*

The optimal policy choice is emphasized. Although the differences in welfare levels are very small, a pattern emerges. Note firstly, if m is high such that $\frac{m}{2}$ is close to the cost difference $c_o - c_g$, a trade ban may dominate the other policies since a ban maximizes the aggregate consumer benefits from GM-free products (top row above).

Secondly, no regulation may be the optimal policy if m is low such that $\frac{m}{2}$ is close to the other cost difference $c_o - c_g/\alpha$. Even if the domestic firm would still adopt the label, the benefits will be to small compared to the higher costs (the row in the middle above).

Thirdly, if α is lower such that $\frac{m}{2}$ is well above the cost difference $c_o - \frac{c_g}{\alpha}$, a GM-free labeling scheme is likely the optimal policy. With respect to the no regulation case, the reason is both that it allows the domestic firm to

produce GM-free, and hence, to improve its competitive position, and that those consumers that value GM-free products, still are able to buy GM free products (the bottom row above).

Lastly, it is possible to show that in our numerical example a trade ban is protectionist (top row above). The gain in welfare compared with a GM-free labeling scheme is only 0.001, while the foreign firm would have earned 0.003 on a GM-free label scheme compared with a trade ban. On the other hand, the domestic gain with a GM-free labeling scheme compared to no regulation is 0.072, while the loss of the foreign firm is 0.031, that is, smaller than the gain. This also hold for the bottom row: The domestic gain with a GM-free labeling scheme compared to no regulation is 0.016, while the loss of the foreign firm is 0.007. Hence, in both cases, a GM-free labeling scheme cannot be said to be protectionist.

4.4.2 With only local environmental costs

If the domestic country is small, its policy will have little effect on the total growing of GM crops in the rest of the world. It therefore seems natural to assume $D^G(q_d + q_f; Q_w) \approx D^G(q_d; Q_w) \approx D^G(q_f; Q_w) \approx D^G(0; Q_w)$. However, policy can still be believed to have a significant effect on local environmental costs.

When m is high, that is $\frac{m}{2} \geq (c_o - c_g)$, nothing changes. A GM-free labeling scheme is the preferred policy, and such a policy is not protectionist. Clearly, since when $\frac{m}{2} \geq (c_o - c_g)$ the local environmental damages are equal to zero with a labeling scheme, introducing a positive environmental damage can only strengthen the case for a labeling scheme *vis-a-vis* no regulation. Moreover, the labeling scheme has the same effect on environmental costs as a domestic ban, and hence, introducing a positive environmental damage leaves the case for a domestic ban unchanged.

On the other hand, when m is low, that is $\frac{m}{2} < \left(c_o - \frac{c_g}{\alpha}\right)$, no regulation may no longer be the preferred policy. Since when $\frac{m}{2} < \left(c_o - \frac{c_g}{\alpha}\right)$ no firm would choose the GM-free label, a total ban or a domestic ban may be the only alternative. The reason is that both a trade ban and a domestic ban improves the local environment, which enters the social welfare function of the domestic country (see Table 3). While a trade ban could be protectionist since the foreign firm would loose independent of the avoided environmental costs, a domestic ban is not protectionist since the domestic firm would loose on a domestic ban when $\frac{m}{2} < \left(c_o - \frac{c_g}{\alpha}\right)$. In fact this is the only case in which a domestic ban may have some merits.

When m is intermediate, that is, $\left(c_o - \frac{c_g}{\alpha}\right) \leq \frac{m}{2} < (c_o - c_g)$, we still have that a GM–free labeling scheme gives the same outcome as a domestic ban. Hence, we don't have to consider a domestic ban. Further, the case for no regulation becomes weaker while the case for a GM–free labeling scheme and the case for a trade ban both become stronger. Also, since both the labeling scheme and the trade ban eliminates all local environmental damages when $\left(c_o - \frac{c_g}{\alpha}\right) \leq \frac{m}{2} < (c_o - c_g)$, their relative desirability do not change. Let

$D^L(q_d) = (q_d)^2$, and the numerical simulation above changes to:

Table 5: Welfare- only local environmental costs

Conditions	Trade ban	No regulation	GM-free label
$\frac{m}{2} = 0.19$, $c_o - \frac{c_g}{\alpha} = 0.099$	*0.990*	0.683	0.989
$\frac{m}{2} = 0.10$, $c_o - \frac{c_g}{\alpha} = 0.099$	0.900	0.683	*0,916*
$\frac{m}{2} = 0.10$, $c_o - \frac{c_g}{\alpha} = 0.079$	0.900	0.670	*0.916*

Note that no regulation is no longer optimal for any of the cases, and that a GM-free labeling scheme has become optimal for two of the cases. Note also that a trade ban is still protectionist (top row above). (The optimal policy choice is emphasized).

4.4.3 With both local and global environmental costs

Lastly, we consider the case when domestic policy have both local and global environmental consequences, that is $D^G(q_d + q_f; Q_w) > D^G(0; Q_w)$. One reason could be that the domestic country is a major player in the world food market, and hence, its choice of policy will have an effect on the total growing of GM crops.

Strikingly, the optimal choice of policy is still a GM-free labeling scheme when m is high, that is $\frac{m}{2} \geq (c_o - c_g)$. A GM-free labeling scheme is also not protectionist. Clearly, since when $\frac{m}{2} \geq (c_o - c_g)$ both the global and local environmental damages with a GM-free labeling scheme are as low as with a trade ban, nothing changes

While when m is low, that is $\frac{m}{2} < \left(c_o - \frac{c_g}{\alpha}\right)$, the argument for a trade ban becomes further strengthened. If $\frac{m}{2} < \left(c_o - \frac{c_g}{\alpha}\right)$, no firm would choose the GM-free label, and a trade ban is the only alternative that can reduce the part of global environmental costs that stems from foreign growing of GM crops. Again such a policy could be protectionist since the foreign firm looses independent of the avoided environmental costs. A domestic ban is a possible second best solution in this case. It would eliminate the local environmental costs, reduce global environmental costs, and it cannot be protectionist since the foreign firm gains on a domestic ban as long as $\frac{m}{2} < \left(c_o - \frac{c_g}{\alpha}\right)$.

When m is intermediate, that is, $\left(c_o - \frac{c_g}{\alpha}\right) \leq \frac{m}{2} < (c_o - c_g)$, the case for no regulation, the case for a domestic ban and the case for a GM–free labeling scheme all become weaker while the case for a trade ban become stronger. When $\left(c_o - \frac{c_g}{\alpha}\right) \leq \frac{m}{2} < (c_o - c_g)$, again only a trade ban is able to reduce the global environmental costs being caused by foreign growing of GM crops. Let $D^L(q_d) = (q_d)^2$ and $D^G(q_d + q_f; Q_w) = 0.25 * (q_d + q_f)^2$, and the numerical simulation above changes to:

Table 6: Welfare - both global and local environmental costs

Conditions	Trade ban	No regulation	GM-free label
$\frac{m}{2} = 0.19$, $c_o - \frac{c_g}{\alpha} = 0.099$	*0.990*	0.433	0.926
$\frac{m}{2} = 0.10$, $c_o - \frac{c_g}{\alpha} = 0.099$	*0.900*	0.433	0,849
$\frac{m}{2} = 0.10$, $c_o - \frac{c_g}{\alpha} = 0.079$	*0.900*	0.420	0.849

Note that neither no regulation nor a GM-free labeling scheme is any longer optimal for any of the cases, and that a trade ban has become optimal for all the cases. Further, a trade ban is no longer protectionist, since the gain in welfare compared with the other two policy alternatives has become much higher.[9]

5 Products are poorly differentiated *ex ante*

If consumers perceive products to be only weakly differentiated in the horizontal dimension, demand may be *vertically dominated*. One example of this could be cans with corn. In general it is harder to reach unambiguous conclusions with vertical domination. In particular, it is not as straight forward to find the Nash equilibria in the second stage of the game.

In our model *vertical domination* occurs when $m > 2$ (remember that the horizontal differentiation parameter β is fixed at unity). In the Appendix we have solved the model for the case in which $m \geq 3$ and $0 < (c_o - c_g) \leq 3$, which ensures that we have vertical domination, and makes the analysis of the model tractable. Table 7 gives the profits of the domestic and foreign firm in the four possible scenarios:

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[9]On the other hand, it is not uncontroversial to include the reduction in global environmental damages resulting from changes abroad in the domestic welfare function. Trade policies that are motivated by such purposes could be characterized as extraterritorial, see for instance [19]. If the reductions in the foreign growing of GM inputs were not taken into account when comparing domestic welfare in the different scenarios, an eco-label scheme would be optimal for the two bottom rows as in Table 5 above.

Table 7: Market equilibrium profit with vertical differentiation

Market outcome	Domestic firm profit	Foreign firm profit
Scenario 1 GM only	$\frac{1}{2}\left(\frac{3-\frac{c_g}{\alpha}+c_g}{3}\right)^2$	$\frac{1}{2}\left(\frac{3+\frac{c_g}{\alpha}-c_g}{3}\right)^2$
Scenario 2 GM-free only	$\frac{1}{2}$	$\frac{1}{2}$
Scenario 3 Firm d GM-free Firm f GM	$\frac{(2m-c_o+c_g)^2}{9m}$	$\frac{(m+c_o-c_g)^2}{9m}$
Scenario 4 Firm d GM Firm f GM-free	$\frac{(m+c_o-\frac{c_g}{\alpha})^2}{9m}$	$\frac{(2m-c_o+\frac{c_g}{\alpha})^2}{9m}$

Note that if both firms produce GM-free, or both firms produce with GM inputs, profits are as in the horizontal domination case, see Table 1. Then observe that even if only the domestic firm chooses the GM-free label, a GM-free labeling scheme may result in the opposite of protectionism, that is, the foreign firm increases its profit after the GM-free label scheme is introduced. For instance, when $\frac{m}{2} \geq (c_o - c_g)$, the foreign firm, even if it does not adopt the GM-free label, will earn at least $\frac{3}{4}$. This is more than before the labeling scheme was introduced as long as $\frac{c_g}{\alpha} - c_g \lessgtr 0.673$.

While in the *horizontal domination* case we get that both firms adopt the GM-free label as long as m exceeds a critical level, this is not the case with *vertical domination*. When m is high, only one of the firms will adopt the GM-free label as seen from the following table (see Appendix C.2 for more details, among others for the definitions of $\bar{l}_l$ and $\bar{l}_h$):

Table 8: Second stage Nash-equilibriums with GM-free labeling

Benefit from GM-free	Market outcome
$m \in \langle 3, \approx 3.478\rangle$ & $(c_o - c_g) > \bar{l}_h$	Both GM
$m \in \langle 3, \frac{9}{2}\rangle$ & $(c_o - c_g) \leq \bar{l}_l$	Both GM-free
$m > \frac{9}{2}$ or $m \in \langle 3, \frac{9}{2}\rangle$ & $(c_o - c_g) \in \langle \bar{l}_l, \bar{l}_h\rangle$	Firm d GM-free Firm f GM ,or possibly; vice versa

(Note that we always have $\bar{l}_h > \bar{l}_l$)

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The conditions follow an intuitive pattern: If m is low i.e. below ≈ 3.478, and the cost disadvantage of producing GM-free i.e. $(c_o - c_g)$ is high, we will tend to be in a situation in which no firm chooses to adopt the GM-free label. If on the other hand the cost disadvantage of producing GM-free i.e. $(c_o - c_g)$ is low, we may have that both firms adopt the label provided that m is not too high i.e. at least below 4.5.

If m is high i.e. above 4.5 only one firm will choose the label independent of the costs. This will also happen if m is low *and* the cost disadvantage of producing GM-free i.e. $(c_o - c_g)$ is intermediate. Sometimes, we may have two Nash equilibria in pure strategies in the second stage of the game: one in which the domestic firm adopts the GM-free label and the foreign firm does not, and one in which the foreign firm adopts the GM-free label and the domestic firm does not (see Appendix C for more details). To simplify our analysis, in the following we will not consider the equilibrium in which *only* the foreign firm produces GM-free food.

Table 9 lists domestic welfare in the three cases we consider:

Table 9: Domestic welfare - vertical domination

No regulation	$\overline{\Gamma} + \frac{\left(\frac{c_g}{\alpha} - c_g\right)^2}{12} - \left(\frac{5}{6}\frac{c_g}{\alpha} + \frac{c_g}{6}\right)$ $-D^G(1) - D^L(q_d)$
Total ban (or GM-free labeling)	$\overline{\Gamma} + \frac{m}{2} - c_o$
Domestic ban and GM-free labeling	$\bar{\Gamma} + \frac{1}{4} + \frac{m}{3} - c_o + \frac{(c_o - c_g)^2 + 1}{6m} - D^G(q_f; Q_w)$

As for horizontal domination, if m is high enough, the welfare in Scenario 2 "Only GM-free" will dominate welfare in the other two scenarios. This gives rise to the following proposition:

Proposition 5 *When m is high, that is, $m \geq \frac{9}{2}$ and $\frac{m}{2} \geq (c_o - c_g)$, the government prefers a market equilibrium with only GM-free products, and would like to choose a trade ban since Scenario 2 is not attainable through a GM-free label scheme. On the other hand, we can not rule out that a trade ban is protectionist.*

Proof. Let $\frac{m}{2} = c_o - c_g$. We then know that Scenario 2 is preferred to Scenario 1 (see Proposition 2). Then, compare Scenario 2 with Scenario 3: $\Gamma - \frac{7}{12} + \frac{m}{2} - c_o - \Gamma + \frac{1}{3} - \frac{m}{3} + c_o - \frac{(c_o - c_g)^2 + 1}{6m} + D^G(q_f; Q_w) = \frac{3m^2 - 6m - 4}{24m} + D^G(q_f; Q_w) > 0$ for $\forall m \geq 3$. (For the claim about protectionism, see the example below). $\blacksquare$

There is however still a tiny role for a GM-labelling scheme as the following proposition shows:

Proposition 6 *When m is low, that is, $m \in \langle 3, \frac{9}{2} \rangle$ and the cost disadvantage of using GM-free inputs is low, that is, $(c_o - c_g) \leq \sqrt{\frac{9m}{2}} - m$, a GM-free labeling scheme is the preferred policy, and such policy is not protectionist.*

Proof. First, note that when $(c_o - c_g) \leq \sqrt{\frac{9m}{2}} - m$, we have $\frac{m}{2} > c_o - c_g$ for $m \in \langle 3, \frac{9}{2} \rangle$. We then know that Scenario 2 is preferred to Scenario 1 (see proof Proposition 2), and that Scenario 2 is preferred to Scenario 3 (see proof proposition above). Lastly about protectionism, see proof Proposition 2. ∎

We also note from Table 8 that for a high m, welfare in Scenario 3 will dominate welfare in Scenario 1 (only GM). Hence, when m is high, the GM-free label scheme is a sort of second-best policy in the vertical domination case.

With respect to the other cases, that is, m is intermediate/low and the cost disadvantage of GM-free products is intermediate/high, it is more difficult to compare welfare levels in the vertical differentiation case. However, simulation results show that the optimal policy tend to follow the same pattern as for horizontal domination.

In Table 10 we look at three cases in a simple numerical model. Let $m \in [3, 4.5]$, $\Gamma = 10$, $c_o = 9$, $c_g = 6$, $\alpha = 0.95$ and $D^G(1) = D^G(q_f) = D^L(q_d) = 0$. We then have:

Table 10: Welfare - no environmental costs

Conditions	Trade ban	No regulation	GM-free label
$m = 3$, $(c_o - c_g) > \bar{l}_h$	22.50	*23.75*	-
$m = 3.25$, $(c_o - c_g) < \bar{l}_h$	22.63	*23.75*	22.85
$m = 4.5$, $(c_o - c_g) < \bar{l}_h$	*23.25*	22.94	23.12

According to Table 7, when $m = 3$, no regulation yields the highest welfare and no firm would have chosen to adopt the eco-label if it had been introduced. When $m = 3.25$, no regulation still yields the highest welfare, however, note that the domestic firm would have chosen to produce GM-free if a GM-free label had been offered. However, such labeling policy would have yielded lower welfare due to the high cost of GM-free products compared to m i.e. $\frac{m}{2} < (c_o - \frac{c_g}{\alpha})$.

Lastly, when $m = 4.5$, both products being GM-free yields the highest welfare. Since a GM-free labeling scheme would result in only one of the firms producing GM-free,, the government sets a trade ban to make sure there are only GM-free food in the market. However, such ban must be characterized as protectionist since the gain in welfare is only $23.25 - 23.12 = 0.13$, while it can be shown that the loss in foreign profit is 0.63.

6 Conclusion and discussion

Given that consumers' willingness to pay for GM-free food is high compared to the cost disadvantage of GM-free inputs, our results show that the merits of a GM-free labeling scheme is determined by the extent to which the food products are horizontally differentiated *before* the GM-free labeling scheme is introduced. In a market in which food products are well differentiated from the start, a GM-free labeling policy is likely to be the optimal choice for the domestic government independent of the environmental damage. Further, as long as consumers' willingness to pay for GM-free food is high compared to the cost disadvantage of GM-free inputs, such policy is not protectionist. On the other hand, in a market in which food products historically are poorly differentiated, a GM-free labeling policy is likely not optimal. Instead, the government should set a trade ban, which may be protectionist.

The main results for the case in which food products are well differentiated *ex ante* are briefly summarized in the Table 11 below:

Table 11: Optimal policy with historically well differentiated products

Private WTP Environmental costs	$\frac{m}{2} \geq (c_o - c_g)$	$\left(c_o - \frac{c_g}{\alpha}\right) \leq \frac{m}{2}$ $< (c_o - c_g)$	$\frac{m}{2} < \left(c_o - \frac{c_g}{\alpha}\right)$
No environmental costs	GM-free labeling	Ambiguous (GM-free labeling optimal under certain conditions)	No regulation
Only local environmental costs	GM-free labeling	Same as above	Ambiguous (domestic ban optimal under certain conditions)
Both local and global environmental costs	GM-free labeling	Same as above (but trade ban becomes optimal in more cases)	Same as above (but trade ban becomes optimal in more cases)

In a market in which the food products are historically poorly differentiated i.e. there is vertical domination, we get very different results:

Table 12: Optimal policy with historically poorly differentiated products

Private WTP Environmental costs	$m \geq \frac{9}{2}$ & $\frac{m}{2} \geq (c_o - c_g)$	$m \in \langle 3, \frac{9}{2} \rangle$ & $(c_o - c_g) \leq \bar{l}_l$	All other cases
No environmental costs	Trade ban	GM-free labeling	Ambiguous (no regulation tends to be optimal)
Only local environmental costs	Trade ban	GM-free labeling	Ambiguous (domestic ban/GM-free labeling tends to be optimal)
Both local and global environmental costs	Trade ban	GM-free labeling	Ambiguous (trade ban tends to be optimal)

Certainly, our conclusion is based on a special model from the industrial organization literature, and the model clearly has its limitations: There are only two firms in each market, there is unit demand of consumers and full coverage of the market, firms have constant marginal cost etc. On the other hand, the paper points to a possible serious limitation of voluntary approaches to public policy; if markets are poorly differentiated *ex ante*, only a limited number of firms will choose to adopt the desirable production practice. Further, as important, it indicates that policy measures that do not force firms to produce by certain standards are less prone to be protectionist.

Notice also that the costs of regulation on GM food are not present in our model. Some costs can be as small as negligible, for example label making, label-related paper work, or extra specifications/descriptions. While other costs may be substantial. For instance, the procedures of segregation can be extremely complicated and costly, and the cost of such screening always constitutes a significant percentage of the total cost. Some data shows that non-GM soya beans exporting to Japan command a premium of around 10% [?], mainly due to the strict and costly segregation procedure.

Taking into account the significant regulation costs, the threshold of the revenue for firms to adopt GM-free labeling will increase to cover such costs. As a result, a higher premium will be commanded by GM-free food. The sufficient consumers' willingness to pay for such food in turn needs to be higher. Nonetheless, the generality of our results will not be affected by these simplifications, at least as long as regulation costs can be regarded as variable costs. In this case the problem can be solved by increasing the cost of producing GM-free i.e. increasing c_o.

We have argued that under no regulation both firms would produce with GM inputs even if they could benefit from producing GM-free. Clearly, firms must be able to convince consumers that they produce GM-free in order for consumers to be willing to pay a premium. A GM-free labeling scheme that is sponsored by the government solves this, but so could possibly also a private GM-free labeling scheme. Further, one should expect such a scheme to emerge as long as at least one of the firms could benefit from such a scheme. In this case the policy "no regulation" could lead to the same outcome as the policy "GM-free labeling scheme".

On the other hand, a labeling scheme has many of the same characteristics as a natural monopoly, that is, high fixed costs among others connected to building consumer awareness about the scheme, and likely low constant marginal costs i.e. the cost of providing the label to an additional firm. Further, having many competing schemes could also be confusing the consumer. We therefore think it is reasonable to assume that the government will provide the scheme, and that the government crowds out any potential private contestants.

Finally, we have only looked at a uniform distribution of λ i.e. consumers' subjective belief about the seriousness of the potential risks of GM inputs. If the real distribution is more skewed such that some consumers value GM-free food highly, and other consumers do not care, we would expect the scenario with different products with respect to GM-content to become more desirable. Likely, this would also be the outcome of the second stage game in the GM-free labeling case such that GM-free labeling would keep much of its merits. However, as long as we have not analyzed this case, we will have to return to this case in future research.

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A   Demand functions

A.1   With no vertical differentiation

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

$$q_d = \frac{1 - p_d + p_f}{2}, \ q_f = 1 - q_d = \frac{1 + p_d - p_f}{2}. \tag{10}$$

A.2   With vertical differentiation, and horizontal domination

When product d is GM-free while product f is GM, the marginal consumers are located on the line: $\lambda_z^* = \frac{2}{m}(x_{z^*} + \frac{p_d - p_f - 1}{2})$, $m > 0$, 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 square:

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

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

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

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

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

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 $x = \frac{m-p_d+p_f+1}{2}$, $\frac{m-p_d+p_f+1}{2} \geqslant 1$. The demand for Product d is:

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

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

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

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

Since we assume that the market is fully covered, the demand for Product f is: $q_f = 1 - q_d$.

A.3 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 λ-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:

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

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:

$$q_d = \begin{cases} \frac{[m-p_d+p_f+1]^2}{4m} & \text{for } m + p_f - 1 \leqslant p_d \leqslant m + p_f + 1 \\ \frac{m-p_d+p_f}{m} & \text{for } p_f + 1 < p_d < m + p_f - 1 \\ \frac{4m-(p_f-p_d-1)^2}{4m} & \text{for } p_f - 1 \leqslant p_d \leqslant p_f + 1 \end{cases} \qquad (12)$$

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

B Third-stage Nash equilibriums

B.1 Both GM/both GM-free

Demand is given from (10). Each i firm maximizes:

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

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

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

B.2 Domestic GM-free/foreign GM - horizontal domination

We assume that the unique equilibrium is located on the intermediate segment of the demand functions 11 (See Neven and Thisse [22] for a proof of Nash-equilibrium uniqueness). Assume that the domestic firm produces GM-free. We then have that firms maximize:

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

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

The Bertrand-Nash equilibrium prices are:

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

We have to check if the equilibrium prices are consistent with the condition: $m + p_f - 1 < p_d < p_f + 1$ (see 11). This results in the following condition: $m \leqslant \min\left\{3 - c_o + c_g, \frac{3+c_o-c_g}{2}\right\}$. Thus, if $m, (c_o - c_g) \in \left[0, \frac{3}{2}\right]$ the condition will always be fulfilled. The associated Nash equilibrium outputs and profits of each firm are therefore:

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

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

In the case in which the foreign firm produces GM-free, we obtain expressions for outputs and profits that are just mirror images of the expressions above (instead of c_g we have $\frac{c_g}{\alpha}$).

B.3 Domestic GM-free and foreign GM - vertical domination

Again, we assume that the domestic firm produces GM-free, and that the unique Nash-price equilibrium is on the intermediate segment of the demand functions (12) (See Neven and Thisse [22] 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:

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

The set of prices constitutes a Nash equilibrium as long as: $m > \max\left\{3 - c_o + c_g, \frac{3 + c_o - c_g}{2}\right\}$. Notice that this condition is always fulfilled when $m > 3, \forall (c_o - c_g) \in (0, 3]$. We then obtain the Nash-equilibrium outputs and profits of each firm as follows:

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

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

In the case in which the foreign firm produces GM-free, we obtain expressions for profits that are just mirror images of the expressions above (instead of c_g we have $\frac{c_g}{\alpha}$).

C   Equilibria in the second stage of the game

As a tie-breaking rule we assume that the firms adopt the GM-free label if profits are equal or higher with the GM-free label than without.

C.1   Horizontal domination

The Nash-equilibrium is *"both firms adopt"* if:

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

and if:

$$\frac{1}{2} \geq \frac{1}{2}\left(\frac{3 - \frac{m}{2} + c_o - c_g}{3}\right)^2.$$

The first condition reduces to: $\frac{m}{2} \geq c_o - \frac{c_g}{\alpha}$, while the second condition reduces to: $\frac{m}{2} \geq c_o - c_g$. Clearly, the latter is sufficient.

The Nash-equilibrium is *"only the domestic firm adopts"* if:

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

and if:

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

The first condition reduces to: $\frac{m}{2} \geq c_o - \frac{c_g}{\alpha}$, while the second condition reduces to: $\frac{m}{2} < c_o - c_g$. Hence, $\frac{m}{2} \in \left[c_o - \frac{c_g}{\alpha}, c_o - c_g\right\rangle$ ensures that only the domestic firm adopts.

The Nash-equilibrium is *"no firm adopts"* if:

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

and if:

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

The first condition reduces to: $\frac{m}{2} < c_o - \frac{c_g}{\alpha}$, while the second condition reduces to: $\frac{m}{2} < c_o - c_g$. Clearly, the first condition is sufficient.

The Nash-equilibrium is *"only the foreign firm adopts"* if:

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

and if:

$$\frac{1}{2}\left(\frac{3+\frac{m}{2}-c_o+\frac{c_g}{\alpha}}{3}\right)^2 \geq \frac{1}{2}\left(\frac{3+\frac{c_g}{\alpha}-c_g}{3}\right)^2.$$

The first condition reduces to $\frac{m}{2} < c_o - \frac{c_g}{\alpha}$, while the second condition reduces to $\frac{m}{2} \geq c_o - c_g$. Since the two conditions can not be fulfilled at the same time, the outcome *"only the foreign firm adopts"* is not a Nash-equilibrium.

C.2 Vertical differentiation

The Nash-equilibrium is *"both firms adopt"* if:

$$\frac{1}{2} \geq \frac{(m+c_o-\frac{c_g}{\alpha})^2}{9m}, \tag{13}$$

and if:

$$\frac{1}{2} \geq \frac{(m+c_o-c_g)^2}{9m}. \tag{14}$$

Clearly, if (14) holds, (13) must hold. Firstly, note that if $m \geq \frac{9}{2}$, (14) cannot hold as long as $(c_o - c_g) > 0$. Further, as long as $m < \frac{9}{2}$, (14) holds for small values on $(c_o - c_g)$, i.e. we must have $(c_o - c_g) \leq \sqrt{\frac{9m}{2}} - m$. Denote $\sqrt{\frac{9m}{2}} - m$ by $\bar{l}_l$, and note that $\bar{l}_l$ is decreasing in m.

The outcome *"no firm adopts"* is a Nash-equilibrium if:

$$\frac{1}{2}\left(\frac{3-(\frac{c_g}{\alpha}-c_g)}{3}\right)^2 > \frac{(2m-c_o+c_g)^2}{9m}, \tag{15}$$

and respectively for the foreign firm:

$$\frac{1}{2}\left(\frac{3+(\frac{c_g}{\alpha}-c_g)}{3}\right)^2 > \frac{(2m-c_o+\frac{c_g}{\alpha})^2}{9m}. \tag{16}$$

By rearranging the two equations, we get: $3\sqrt{\frac{m}{2}}-2m+(c_o-c_g)-\sqrt{\frac{m}{2}}(\frac{c_g}{\alpha}-c_g)>0$ for (15), and: $3\sqrt{\frac{m}{2}}-2m+(c_o-c_g)+(\sqrt{\frac{m}{2}}-1)(\frac{c_g}{\alpha}-c_g)>0$ for (16). Hence, if (15) holds, (16) must hold. Consequently, we have that *"no firm adopts"* is a Nash-equilibrium if: $(c_o-c_g)>2m-\sqrt{\frac{9m}{2}}+\sqrt{\frac{m}{2}}(\frac{c_g}{\alpha}-c_g)$. Since the left hand side of this equation can be no larger than 3, the highest possible value on m for *"no firm adopts"* to be a Nash-equilibrium is $m\approx 3.478$. Denote $2m-\sqrt{\frac{9m}{2}}+\sqrt{\frac{m}{2}}(\frac{c_g}{\alpha}-c_g)$ by $\bar{l}_h$, and note that $\bar{l}_h$ is increasing in m and $(\frac{c_g}{\alpha}-c_g)$. Note also that we must have $\bar{l}_h>\bar{l}_l$.

The Nash-equilibrium is *"only the domestic firm adopts"* if:

$$\frac{(2m-c_o+c_g)^2}{9m} \geq \frac{1}{2}\left(\frac{3-\frac{c_g}{\alpha}+c_g}{3}\right)^2, \tag{17}$$

The foreign firm will not adopt if:

$$\frac{(m+c_o-c_g)^2}{9m} > \frac{1}{2}. \tag{18}$$

Note that (18) is the reverse of (14). Hence, the outcome *"only the domestic firm adopts"* and *"both firms adopt"* are mutually exclusive. Moreover, that (17) is the reverse of (15), and thus, the outcome *"only the domestic firm adopts"* and *"no firm adopts"* are also mutually exclusive. Since (18) is the reverse of (14) and (17) is the reverse of (15), we have that both equations hold if: $(c_o-c_g)\in\left\langle\sqrt{\frac{9m}{2}}-m, 2m-\sqrt{\frac{9m}{2}}+\sqrt{\frac{m}{2}}(\frac{c_g}{\alpha}-c_g)\right]$. (For instance, if $m=3$ and $(\frac{c_g}{\alpha}-c_g)=0.25$, the interval reads $\langle 0.674, 2.542]$).

The Nash-equilibrium is *"only the foreign firm adopts"* if:

$$\frac{(2m-c_o+\frac{c_g}{\alpha})^2}{9m} \geq \frac{1}{2}\left(\frac{3+\frac{c_g}{\alpha}-c_g}{3}\right)^2, \tag{19}$$

The domestic firm will not adopt if:

$$\frac{(m+c_o-\frac{c_g}{\alpha})^2}{9m} > \frac{1}{2}. \tag{20}$$

Firstly, note that if (20) is true, (13) cannot be true. Hence, the outcome *"only the foreign firm adopts"* and *"both firms adopt"* are mutually exclusive.

Further, note that if (19) is true, (16) cannot be true. Hence, the outcome "no firm adopts" and "only the foreign firm adopts" are also mutually exclusive.

On the other hand, even though $(c_o-c_g) \in \left\langle \sqrt{\frac{9m}{2}} - m, 2m - \sqrt{\frac{9m}{2}} + \sqrt{\frac{m}{2}}(\frac{c_g}{\alpha} - c_g) \right]$ implies that neither (14) nor (15) holds, (13) and/or (16) may still hold. In this case "only the domestic firm adopts" is the only equilibrium. (For instance, if $m = 3$ and $(\frac{c_g}{\alpha} - c_g) = 1$ and $(c_o - c_g) = 2.5$, (19) does not hold while both (18) and (17) hold).

D   Calculating transportation cost

D.1   Both GM/both GM-free

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

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

Solve the integrals and insert for p_i and p_j, we obtain:

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

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

D.2   Domestic GM-free/foreign GM - horizontal domination

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

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

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

Insert $\lambda = \frac{2}{m}(x + \frac{p_d-p_f-1}{2})$ into the equation and solve the integrals: $TC = \frac{1}{12} + \frac{m^2}{12} + \frac{m(p_f-p_d)}{4} + \frac{(p_f-p_d)^2}{4}$. Finally, by inserting for $p_d = \frac{6+m+4c_o+2c_g}{6}$ and $p_f = \frac{6-m+4c_g+2c_o}{6}$ into the equation, we obtain:

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

D.3 Domestic GM-free/foreign GM - vertical domination

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

$$TC = \int\limits_{0}^{1} x^2 \left(1 - \lambda\right) dx + \int\limits_{0}^{1} \left(1 - x\right)^2 \lambda dx.$$

Insert $\lambda = \frac{2}{m}(x + \frac{p_d - p_f - 1}{2})$, $p_d = \frac{2m + 2c_o + c_g}{3}$ and $p_f = \frac{m + c_o + 2c_g}{3}$ into the equation and solve the integrals:

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

E Calculating GM-free benefit

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

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

E.1 Horizontal domination case

$$B = \int\limits_{0}^{\frac{p_f - p_d + 1}{2}} \int\limits_{0}^{1} \lambda m d\lambda dx + \int\limits_{\frac{p_f - p_d + 1}{2}}^{\frac{m + p_f - p_d + 1}{2}} \int\limits_{\frac{2x + p_d - p_f - 1}{m}}^{1} \lambda m d\lambda dx$$

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

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

E.2 Vertical domination case

$$B = \int\limits_{0}^{1} \int\limits_{\frac{2x + p_d - p_f - 1}{m}}^{1} \lambda m d\lambda dx$$

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

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

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