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

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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 with respect to a domestic welfare measure? 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, a labeling policy is likely 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.

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, and in a turn, 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

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[1] The total ban of European Union on GM food and animal feed was in effect from 1999 to 2004[13].

addresses the use of product labeling based on production methods, WTO has been sceptical to mandatory product labeling 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[13]. 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 labelled products has been developed. Lusk and Fox [19] 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 have 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 [31] 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. [5]. 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 or a mandatory labeling scheme 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 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 on taste, texture, packaging design etc. We have therefore chosen to model our representative food market as a Bertrand duopoly with *ex ante* horizontal differentiation. This implies that the producers make positive profits, and there is scope for protectionism i.e. resolving policy such that profit is shifted from the foreign producer to the domestic producer. Moreover, the model also include *ex post* vertical differentiation in product quality. That is, products may become vertically differentiated in addition to horizontally differentiated if producers choose differently with respect to the content of GM inputs in their food products.

As far as we know, Neven and Thisse [24] were the first to analyze a model with both horizontal and vertical differentiation. We build on the application of Neven and Thisse's work found in Greaker [12]. 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 [4] and Amacher et al. [2]. Further, Conrad [6] provides an analysis of consumers' demand for environmental quality in a pure horizontal differentiation model. However, firms in this literature make zero profit *ex ante*, i.e. before the environmental differentiation is introduced making the analysis of protectionism trivial.

We assume that the legislators can choose among the following policy 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.[2]

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 and a voluntary GM-free label is more 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 [10]. Fischer and Serra define a domestic policy measure to be protectionist when the use of it exceeds what a planner would impose if all producers were local. For instance, this would be the case if 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. Further, 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

[2] 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 consumer 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 must pay to obtain a label with a *positive* effect.

avoid GM food is sufficiently high, a labeling policy is never protectionist.

2 Benefits and potential 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[3].

Studies document that adoption of GM on crops results in higher field yield and substantial reduction of the use of chemical sprays[4]. 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 less poison exposure [29]. In this paper, we simply capture the 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.[5]

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 normal 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 all products will be scrutinized before they are released into the market, 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 [20][27].

Another concern related to GM food is that an allergen, a protein that causes an allergic reaction, could be accidentally introduced into a new food

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

[4] 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 [17]. In the US, adoption of GM crops resulted in pesticide use reduction of 45.6 million ponds in 2001[11].

[5] 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"[14]. Thus, there is a fear that the world's food supply will be finally controlled in a few large firms' hands.

products [8][9][28]. Soybeans modified with Brazil nut genes, for instance, have been found to express Brazil-nut proteins of the sort that might trigger allergic reaction [25].

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. [15][22].

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. Further, since no one seems to prefer "unnatural" or "artificial" food, the natural/unnatural property of a food product is also not a matter of horizontal differentiation, but of vertical differentiation.

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", through outcrossing with wild relatives[6]. Both GM crops and traits can generate this potential risk of invasiveness or persistence in wild habitats [33].

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 [23]. As a result, stronger and larger amount of toxins have to be sprayed, triggering a potential vicious circle.

A further worry is over GM plants' effects on non-targeted species. Pollen from GM crops may blow or spill into fields of organic plants and fertilize them [30]. Seeds intended for foodstuffs could also spill, germinate and grow, allowing their genes to enter the ecosystem unintentionally. 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 [3].

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 [18]. 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[26], many still seems to believe that there some chance that GMOs could have such effects [3].

In order to model the potential environmental damages from the use of GM inputs we make the following assumptions: I) The use of GM inputs may

[6] For instance, glyphosate tolerance is now known in rigid ryegrass, a pernicious weed [7].

have global environmental impacts like irreversible loss of genetic material independent of where the GM inputs are grown, II) The use of GM inputs may also have local environmental impacts depending on whether the GM inputs are grown locally or imported, that is, if food made with GM input grown abroad is imported we assume that the local environmental impacts are zero.

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.

Let the variable, μ_z, represent an arbitrary consumer z's willingness to pay to avoid the health-related risks of GM ingredients, and let the variable, γ_z, express the same consumer's willingness to pay to reduce the potential environmental damages from the use of GM ingredients. While μ_z expresses the personal health benefit from avoiding GM food, γ_z gives z's benefit from contributing to a public good, in this case, helping preserving the global environment. The latter is often coined a *warm-glow effect*, see for example Andreoni [1].

We assume that μ_z and γ_z are perfectly correlated for all z. Further, we write an arbitrary consumer z's willingness to pay to avoid food products with GM inputs: $\gamma_z + \mu_z = \lambda_z m$, where $\lambda_z \sim [0, 1]$, reflecting z's subjective belief about the seriousness of the potential risks, and m gives the benefit from GM-free food. Obviously, $m > 0$ when the product is GM-free and $m = 0$ when the product is GM.

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 the domestic market. 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 [32], 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. The domestic firm is located at $(0, 0)$, whereas the foreign firm is located at $(1, 0)$, i.e. at each end of the bottom line in the unit square. Let $x \in [0, 1]$. Then x is the number of consumers in the interval $[0, x]$ along the bottom line in the unit square.

The gross utility of consumer z from consuming one unit of product d at $(0, 0)$ is then:

$$u_z^d = \Gamma - \beta x_z^2 + \lambda_z m \tag{3}$$

where the parameter Γ is a constant utility term, which consumer z derives from consuming one unit of food. It is the same for either type of products and for all the consumers.

The parameter β expresses the strength of consumer z's personal taste in the horizontal dimension such as preferences for food flavour or food packaging design. β is often coined the *transportation cost* parameter. The distance x, or alternatively $[1-x]$, measures how far the consumer is from her ideal product in the horizontal dimension, i.e. along the bottom line of the unit square. The larger the β, the more weight consumers place on products' horizontal differentiation.

The GM-free quality of a product is a *credence attribute*. The quality of credence goods cannot be observed either at the time of purchase or after consumption. Hence, consumer z will not receive the benefit $\lambda_z m$ unless she can be sure that the product is really GM free. Clearly, she can be sure if a GM-free label is observed on the product or if GM food is banned by the government.

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

$$u_z^f = \Gamma - \beta_z(1-x_z)^2 + \lambda_z m \tag{4}$$

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

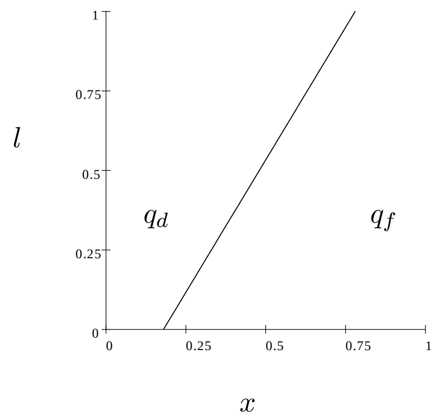
Let cs denote individual consumer's surplus, which is the difference between consumer's willingness to pay and the price actually paid, i.e. $cs_z^i = u_z^i - p_i$, $i = d, f$. Consumers make their purchase decisions by maximizing their surplus. We call consumers who are indifferent between buying product d and f *marginal consumers*, namely z^*. The marginal consumers can be found by equalizing the surpluses from buying product d and from product f:

$$\begin{array}{ll} x_{z^*} = \frac{1-p_d+p_f}{2}, \forall\lambda & \text{when } d = f \text{ w.r.t. GM content} \\ \lambda_{z^*} = \pm\frac{2}{m}(x_z + \frac{p_d-p_f-1}{2}) & \text{when } d \neq f \text{ w.r.t. GM content}^7 \end{array}. \tag{5}$$

It is evident that inside the unit square, all the consumers to the left of the line defined by (5) prefer to buy the domestic product, whereas all the consumers to the right of the line defined by (5) buy the foreign product. The following figure shows the case in which the domestic firm produces GM-free and the foreign firm produces with GM inputs:

Figure 1. The division of the market.

[7] The sign is positive when product d is GM-free and product f is GM, and negative if *vice versa*.



Consumers putting much weight on the GM-free attribute, that is, having a high λ, will tend to buy from the domestic producer placed at 0 even though they are closer to the foreign product placed at 1. Note that when both firms produce with GM inputs, or when both firms produce GM-free, the line separating the unit square will be vertical.

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 preffered 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 the 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:

$$\widetilde{D} = \begin{cases} D^G(q_d + q_f; Q_w) + D^L(q_d) & \text{if both } d \text{ and } f \text{ are GM} \\ D^G(q_d; Q_w) + D^L(q_d) & \text{if only } d \text{ are GM} \\ D^G(q_f; Q_w) & \text{if only } f \text{ are GM} \\ D^G(0; Q_w) & \text{if both } d \text{ and } f \text{ are GM-free} \end{cases} \tag{6}$$

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:

$$W_d = \Gamma - TC + B - p_d q_d - p_f q_f + \pi_d - \widetilde{D}, \tag{7}$$

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 (7) 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:

$$W_f = \pi_f. \tag{8}$$

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

4 Horizontal domination case

When consumers make their purchase decisions, if they put more weight on products' horizontal aspects relative to the vertical aspect represented by the value on m, 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 case in the next section. Since β is fixed to unity, m cannot be too high. Let $0 \leq m \leq \frac{3}{2}$ and $(c_o - c_g) \in (0, 1]$, which ensures that we have horizontal domination.

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 [32], 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 have the same price level 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 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).

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. Since "GM-free" is a credence attribute, there is no way for consumers to separate a GM-free product from a GM one without some kind of labelling. Further, we assume that firms cannot commit to produce GM-free without some kind of guarantee from the government that products really are GM-free. Thus, if the government restrains from regulation (Policy alternative IV), the representative food market we are looking at will reassemble 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

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

Table 1: Market equilibrium profits

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 GM-free / 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 GM / GM-free	$\frac{1}{2}\left(\frac{3-\frac{m}{2}+c_o-\frac{c_g}{\alpha}}{3}\right)^2$	$\frac{1}{2}\left(\frac{3+\frac{m}{2}-c_o+\frac{c_g}{\alpha}}{3}\right)^2$

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, 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 equilibrium (see Appendix C for more details). Note that the term $\frac{m}{2}$ represents the average benefit, 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: The second-stage equilibriums under an eco-labeling policy

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

Notice 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.

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 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 cannot do worse than adopting the GM-free label, which will result in the same outcome as a trade ban.

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 labelling 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: Welfare

Policy	Domestic welfare
No regulation *and* GM-free labeling if $\frac{m}{2} < \left(c_o - \frac{c_g}{\alpha}\right)$	$\overline{\Gamma} + \frac{\left(\frac{c_g}{\alpha} - c_g\right)^2}{12} - \left(\frac{5}{6}\frac{c_g}{\alpha} + \frac{c_g}{6}\right)$ $-D^G(1) - D^L(q_d)$
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 $c_o > (\frac{5}{6}c_o + \frac{c_g}{6}) > (\frac{5}{6}\frac{c_g}{\alpha} + \frac{c_g}{6})$.

The optimal policy of the domestic government will depend on the relative magnitude of $\frac{m}{2}$, $(c_o - c_g)$, $(\frac{c_g}{\alpha} - c_g)$, 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, either we are in a situation in which domestic policy has no effect on the level of environmental damages, or in a situation in which the subjective beliefs of the domestic government is equal to the beliefs of the foreign government.

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 $\frac{c_g}{\alpha} < c_o$.

Compare a domestic ban with a GM-free labeling scheme: Let $\frac{m}{2} = (c_o - c_g)$, and we have $\left[\overline{\Gamma} + \frac{m}{2} - c_o\right] - \left[\overline{\Gamma} + \frac{5m}{12} - (\frac{5}{6}c_o + \frac{c_g}{6}) - \frac{m^2 + 2m(c_o - c_g) - 2(c_o - c_g)^2}{72}\right] = \frac{(c_o - c_g)^2}{12} > 0$.

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 no less 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. 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 labelling 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: $\left[\overline{\Gamma} - \frac{10\frac{c_g}{\alpha}+2c_g-\left(\frac{c_g}{\alpha}-c_g\right)^2}{12}\right] - \left[\overline{\Gamma} + \frac{5m}{12} - (\frac{5}{6}c_o + \frac{c_g}{6}) - \frac{m^2+2m(c_o-c_g)-2(c_o-c_g)^2}{72}\right] = \frac{3(c_g/\alpha-c_g)^2+2(c_o-c_g/\alpha)^2+2(c_o-c_g/\alpha)(c_o-c_g)-(c_o-c_g)^2}{36} > 0$ 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 labelling 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: Simulation results in the horizontal domination case

Conditions	W_d-ban	W_d-nr	W_d-ec
$\frac{m}{2} = 0.19,\ c_o - \frac{c_g}{\alpha} = 0.099$	*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 ban (W_d-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 labelling scheme (W_d-ec) 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 labelling 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 labelling 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 labelling scheme compared to no regulation is 0.016, while the loss of the foreign firm is 0.007. Moreover, the foreign firm's loss would be higher with a trade ban.

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 labelling scheme, introducing a positive environmental damage can only strengthen the case for a labelling scheme *vis-a-vis* no regulation. Moreover, the labelling 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 labelling 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: Simulation results in the horizontal domination case

Conditions	W_d-ban	W_d-nr	W_d-ec
$\frac{m}{2} = 0.19$, $c_o - \frac{c_g}{\alpha} = 0.099$	*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 labelling scheme has become optimal for two of the cases. Note also that a trade ban is still protectionist (top row above).

4.4.3 With both local and global environmental costs

We now assume that $D^G(q_d + q_f; Q_w) > D^G(0; Q_w)$, that is, 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 labelling 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 labelling 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: Simulation results in the horizontal domination case

Conditions	W_d-ban	W_d-nr	W_d-ec
$\frac{m}{2} = 0.19$, $c_o - \frac{c_g}{\alpha} = 0.099$	*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 labelling 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 Vertical domination case

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. We will therefore focus on the major differences compared to horizontal domination.

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 $(c_o - c_g), (c_o - \frac{c_g}{\alpha}) \in \langle 0, 3 \rangle$. Table 7 gives the profits of the domestic and foreign firm when there is vertical differentiation ex post. If on the other hand either both firms produce GM-free, or both firms produce with GM inputs, profits are as in Table 1.

Firstly, note that if a GM-free label is introduced, and if $\frac{m}{2} \geq (c_o - c_g)$, at least one of the firms will always choose to produce GM-free. This is easily seen from the fact that $\frac{(2m - c_o + c_g)^2}{9m} > \frac{1}{2}$ when $\frac{m}{2} = (c_o - c_g)$ and $m \geq 3$.

More importantly, 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. In fact, 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

[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 by some be characterized as extraterritorial. 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 profits in vertical domination case

Market outcome	Domestic firm profit	Foreign firm profit
Scenario 3 GM-free / GM	$\frac{(2m-c_o+c_g)^2}{9m}$	$\frac{(m+c_o-c_g)^2}{9m}$
Scenario 4 GM / GM-free	$\frac{(m+c_o-\frac{c_g}{\alpha})^2}{9m}$	$\frac{(2m-c_o+\frac{c_g}{\alpha})^2}{9m}$

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.

This does not imply that a GM-free labelling scheme necessarily is protectionist. We have the following proposition:

Proposition 5 *When $\frac{m}{2} \geq (c_o - c_g)$, firms will choose to produce differently if an eco-label is provided. The foreign firm, even if it does not adopt the GM-free label, will earn at least $\frac{3}{4}$. Hence, for all α satisfying $\frac{c_g}{\alpha} - c_g < \frac{3(\sqrt{3}-\sqrt{2})}{\sqrt{2}}$, the foreign firm will improve its profit with a labeling scheme, and consequently, a label scheme cannot be protectionist.*

Thus, as long as costs are not too asymmetric, the effect of a GM-free label will be the opposite of protectionism.

Table 8 lists domestic welfare in the case in which only the domestic firm adopts the GM-free label. The outcomes with no regulation or a trade ban are identical with the horizontal differentiation case, see Table 3.

Table 8: Welfare in vertical domination case

Market outcome	Domestic welfare
Scenario 3 GM-free / GM	$\bar{\Gamma} + \frac{1}{4} + \frac{m}{3} - c_o + \frac{(c_o-c_g)^2+1}{6m} - D^G(q_f; Q_w)$

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 6 *When m is high, that is, $\frac{m}{2} \geq (c_o - c_g)$, 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 1). 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 $m \geq 3$. Both firms choosing the GM-free label is only an equilibrium if $\frac{(m+c_o-c_g)^2}{9m} < \frac{1}{2} \iff \frac{m^2}{4} < \frac{1}{2}$, which cannot be true for $m \geq 3$. Lastly, all higher values of $\frac{m}{2}$ will make Scenario 2 even more preferred. (For the claim about protectionism, see the example below). ■

We also note from Table 3 and 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 two other cases, that is, m is intermediate or low, it is more difficult to compare welfare levels in the vertical differentiation case, partly because even if $\frac{m}{2} < (c_o - \frac{c_g}{\alpha})$, one of the firms may still choose to produce GM-free when a GM-free label is offered. However, simulation results show that the optimal policy tend to follow the same pattern as for horizontal domination when $\frac{m}{2} < (c_o - c_g)$. In Table 7 below we illustrate Proposition 5 together with the two other cases $\frac{m}{2} \in \left[(c_o - \frac{c_g}{\alpha}), (c_o - c_g)\right\rangle$ and $\frac{m}{2} < c_o - \frac{c_g}{\alpha}$ by a numerical model. Let $m \in [3, 4]$, $\Gamma = 10$, $c_o = 9$, $c_g = 7$, $\alpha = [0.9, 0.95]$ and $D^G(1; Q_w) = D^G(q_f; Q_w) = D^L(q_d) = 0$. We then have:

Table 9: Simulation results in vertical domination case

Conditions	W_d-ban	W_d-nr	W_d-ec
$\frac{m}{2} \geq (c_o - c_g)$	*3.00*	2.40	2.79
$\frac{m}{2} \in \left[(c_o - \frac{c_g}{\alpha}), (c_o - c_g)\right\rangle$	2.50	2.40	*2.53*
$\frac{m}{2} < c_o - \frac{c_g}{\alpha}$	2.50	*2.70*	2.53

According to Table 7, when m is high, both products being GM-free yields the highest welfare 3.00. Since an eco-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 $3.00 - 2.79 = 0.21$, while it can be shown that the loss in foreign profit is 0.29.

When m is intermediate, the GM-free labeling yields the highest welfare 2.53. Further, this policy is not protectionist. In fact, the foreign firm gains from the policy even if it continues to produce with GM. The reason is the increased product differentiation which allows a higher markup on cost.

Finally, when m is low, no regulation yields the highest welfare 2.70. 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 increased markup over costs and the small m.

6 Conclusion and discussion

Our preliminary results show that the merits of a GM-free labeling scheme is to a large extent determined by the way the food products are differentiated, the consumers' willingness to pay for GM-free quality, and the environmental damage GM inputs may generate.

In a market in which food products are well differentiated from the start, when the consumers' willingness to pay for GM-free food is sufficiently high, an eco-labeling policy is likely to be an optimal option for the domestic government independent of the environmental damage. Such policy is not protectionist. While when the consumers' willingness to pay for GM-free food is very low and the perceived environmental damages from GM crops are low, no regulation is the preferred policy.

Things are more complicated when consumers' willingness to pay is intermediate, and/or there are either pure local or both local and global negative environmental effects. Although no general ranking can be made, under certain conditions of m and α and with only local environmental effects of policy, GM-free labeling is better than both no regulation and a trade ban, and the GM-free labeling policy is not necessarily protectionist. The main results for the case in which food products are well differentiated *ex ante* are briefly summarizes in the table below:

Table 10: Optimal policy alternatives under horizontal domination

Private WTP Environmental costs	$\frac{m}{2} \geq (c_o - c_g)$	$\frac{m}{2} < (c_o - c_g)$ & $\frac{m}{2} \geq \left(c_o - \frac{c_g}{\alpha}\right)$	$\frac{m}{2} < (c_o - \frac{c_g}{\alpha})$
$D^G(1) = D^L(q_d) = 0$	GM-free labelling	Ambiguous (GM-free labelling may be optimal under certain conditions)	No regulation
$D^G(q_d + q_f) = 0$ but $D^L(q_d) \geq 0$	GM-free labelling	Same as above	Ambiguous (domestic ban may be optimal under certain conditions)
$D^G(q_d + q_f) \geq 0$ & $D^L(q_d) \geq 0$	GM-free labelling	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 where the food products are poorly differentiated *ex ante* i.e. there is vertical domination, and the consumers' willingness to pay for GM-free food is high, it is optimal for the domestic government to set a trade ban to insure the "GM-free only" outcome which is not attainable through the other alternatives. Hence, with respect to Table 7 above, in the second column "GM-free labelling" would have to be replaced with "trade ban" in all the cells. Further, for this case, a trade ban is likely not protectionist.

Certainly, our conclusion is based on a number of simplified assumptions, such as the number of firms is limited to two in each market, unit demand of consumers, full coverage of the market, no sunk costs involved in production, etc. Also notice 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% [16], 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 eco-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 labelling scheme that is sponsored by the government solves this, but so could possibly also a private GM-free labelling 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 labelling scheme".

On the other hand, a labelling 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, variable $\lambda_z m$ is used in our paper to represent an arbitrary consumer z's willingness to pay for avoiding GM inputs in food products. Put it in another way; it is the both the warm-glow from helping the environment and the reduced risk of potential negative health effects. The optimal policy alternative depends on the relative value of m. There is no problem for us to accept that $m = 0$ when food is GM-contained and $m > 0$ when food is GM-free. However, which value of m is more suitable and closer to the reality? Further studies and experiments need to be done to answer these questions.

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Appendix

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:

$$q_d = \frac{1 - p_d + p_f}{2}, \; q_f = 1 - q_d = \frac{1 + p_d - p_f}{2}. \tag{9}$$

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:

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

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

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

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:

$$q_d^{3h} = 1 - \int\limits_{\frac{p_d - p_f - 1}{2}}^{1} \left[\frac{2}{m}(x + \frac{p_d - p_f - 1}{2}) \right] dx = \frac{4m - (p_f - p_d - 1)^2}{4m},$$

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

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

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

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:

$$q_d = 1 - \int\limits_{0}^{1} \left[\frac{2}{m}(x + \frac{p_d - p_f - 1}{2}) \right] dx,$$

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:

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

The demand for product f is simply: $q_f = 1 - q_d^{3v}$.

B Third-stage Nash equilibriums

B.1 Both GM/both GM-free

Demand is given from (9). 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 10 (See Neven and Thisse [24] 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 10). 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 $m \in \left[0, \frac{3}{2}\right]$ and $0 < c_o - c_g \leqslant 1$,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 (11) (See Neven and Thisse [24] 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: $\frac{m(\bar{r}_c)}{2} < c_o - \frac{c_g}{\alpha}$, 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:

$$\frac{1}{2} \geq \frac{(m + c_o - \frac{c_g}{\alpha})^2}{9m}, \tag{12}$$

and if:

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

Clearly, if (13) holds, (12) must hold. Further, as long as $m < \frac{9}{2}$, (13) holds for small values on $(c_o - c_g)$.

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

$$\frac{(2m - c_o + c_g)^2}{9m} \geq \frac{1}{2} \left(\frac{3 - \frac{c_g}{\alpha} + c_g}{3} \right)^2, \tag{14}$$

The foreign firm will not adopt if:

$$\frac{(m + c_o - c_g)^2}{9m} > \frac{1}{2}. \tag{15}$$

Firstly, note that as long as $\frac{m}{2} \geq (c_o - c_g)$ and $m > 3$, both conditions will always be fulfilled. Note also that (15) is the reverse of (13). Hence, the outcome *"only the domestic firm adopts"* and *"both firms adopt"* are mutually exclusive.

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

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

The domestic firm will not adopt if:

$$\frac{(m + c_o - \frac{c_g}{\alpha})^2}{9m} > \frac{1}{2}. \tag{17}$$

Firstly, note that if (17) is true, (12) cannot be true. Hence, the outcome *"only the foreign firm adopts"* and *"both firms adopt"* are also mutually exclusive. Secondly, observe that both (16) and (17) is fulfilled if for instance we have; $m = 3$, $\alpha = 0.9$ and $c_o - \frac{c_g}{\alpha} = 1$. Hence, the Nash-equilibrium *"only the foreign firm adopts"* is possible.

Finally, the outcome *"no firm adopts"* is a Nash-equilibrium if:

$$\frac{1}{2}\left(\frac{3 - \frac{c_g}{\alpha} + c_g}{3}\right)^2 > \frac{(2m - c_o + c_g)^2}{9m}, \tag{18}$$

and respectively for the foreign firm:

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

Firstly, note that if (19) is true, (16) cannot be true. Hence, the outcome *"only the foreign firm adopts"* and *"no firm adopts"* are also mutually exclusive. Secondly, observe that both (18) and (19) is fulfilled if for instance we have; $m = 3$, $\frac{c_g}{\alpha} - c_g = 0.1$ and $c_o - c_g = 3$. Hence, the Nash-equilibrium *"no firm adopts"* is possible.

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:

$$TC = \int_{0}^{\frac{p_f - p_d + 1}{2}} x^2 dx + \int_{\frac{p_f - p_d + 1}{2}}^{\frac{m + p_f - p_d + 1}{2}} x^2 (1 - \lambda) dx$$
$$+ \int_{\frac{p_f - p_d + 1}{2}}^{\frac{m + p_f - p_d + 1}{2}} (1 - x)^2 \lambda dx + \int_{\frac{m + p_f - p_d + 1}{2}}^{1} (1 - x)^2 dx.$$

Insert $\lambda = \frac{2}{m}(x + \frac{p_d - p_f - 1}{2})$ 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:

$$TC = \int_{0}^{1} x^2 (1 - \lambda) dx + \int_{0}^{1} (1 - x)^2 \lambda dx.$$

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

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

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

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

E.2 Vertical domination case

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

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

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