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Abstract

The emergence of agricultural biotechnology and the subsequent introduction of genetically modified organisms (GMOs) into the food system have been among the most controversial issues surrounding the increasingly scrutinized agri-food system. They have received considerable attention in the economics literature with the main focus being on the optimal regulatory response to products of biotechnology. This paper builds on the literature on the regulation of products of biotechnology by placing the analysis of labeling decisions in a multi-country context. Specifically, the objective of this study is to examine the effect of the strategic interdependence between countries on their regulatory responses to products of biotechnology. The paper analyzes the strategic effects of national regulatory decisions on labeling of GM products and identifies the determinants of the non-cooperative Nash equilibrium labeling regimes in a small number of producing countries that supply the world market of an agricultural product. Analytical results show that the Nash equilibrium configuration of labeling regimes in countries that have adopted the GM technology depends on (i) the distribution of consumer preferences and the level of consumer aversion to GM products; (ii) the size of the segregation and labeling costs in these countries; (iii) the relative productive efficiency and the cost effectiveness of the GM technology; (iv) the market power of the life science companies; and (v) the strength of intellectual property rights in these countries.

KEYWORDS: biotechnology, genetically modified organisms, labeling, strategic behavior, trade

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1. Introduction

The emergence of agricultural biotechnology and the subsequent introduction of genetically modified organisms (GMOs) into the food system have been among the most controversial issues surrounding the increasingly scrutinized agri-food system. While agricultural producers have responded to the agronomic benefits associated with the producer-oriented, first generation of GM products and have been adopting GM crops in increasing numbers (James, 2003), consumers around the world have expressed an aversion to food products containing GM ingredients. Consumer opposition to GM products varies significantly both between and within countries and is founded on health, environmental, ethical and/or philosophical concerns about agricultural biotechnology (The Economist, 1999; Giannakas and Fulton, 2002).

Similarly diverse have been the countries' regulatory responses to GMOs with the issue of labeling being a focal point in policy forums around the world. For instance, while the United States (US) opposes the labeling of GM products arguing the "substantial equivalence" between the current, producer-oriented GM products and their conventional counterparts, the European Union has introduced mandatory labeling of GM products on the basis of its "precautionary principle" and the expressed consumer aversion to these products (see Sheldon (2004) for a comprehensive review of the policy debate between the EU and the US on the regulation of GMOs. On the labeling of GM products see also Caswell (1998), Runge and Jackson (2000), Crespi and Marette (2003), Fulton and Giannakas (2004), and Lapan and Moschini (2004)).

Consumer opposition to GM products (or its lack thereof) is often cited as the primary force behind countries' decisions on the labeling of these products. While consumer reaction is certainly important, there are other factors that are also significant in shaping the regulatory responses to products of biotechnology. In particular, given the high volume of trade of agricultural and food products and the intense competition between the major suppliers for access in the world market, a country's decision on its labeling regime can be expected to affect and be affected by the regulatory and labeling regimes of the other major suppliers of the product(s) in question. Interestingly, this strategic interdependence between the major producers of agri-food products has, to our knowledge, been ignored by the relevant literature.

The objective of this paper is to examine the effect of the strategic interdependence between countries on their regulatory responses to products of biotechnology. In particular, the paper analyzes the strategic effects of national regulatory decisions on labeling of GM products and identifies the determinants of the non-cooperative Nash equilibrium labeling regimes in a small number of producing countries that supply the world market of an agricultural product.

When compared to previous research, this study relates more closely to the work by Fulton and Giannakas (2004) that analyzes the market and welfare effects of the introduction of GM technology under different regulatory and labeling regimes. Specifically, our analysis of producer and consumer behavior utilizes the methodological framework developed in Fulton and Giannakas (2004). Unlike Fulton and Giannakas (2004), however, our study explicitly accounts for the strategic interactions among countries by placing the labeling decision in a multi-country context.

The rest of the paper is organized as follows. Section 2 discusses the methodology and assumptions employed in our analysis. Sections 3 and 4 examine the producer and consumer decisions under alternative labeling regimes. Section 5 derives the equilibrium conditions in the world market under different scenarios on the labeling policies of the GM producing countries. Section 6 derives the payoff matrix of the game and identifies the conditions that facilitate alternative Nash equilibria in labeling strategies. Section 7 summarizes and concludes the paper.

2. Methodology and Assumptions

Our stylized model considers three producing regions that supply the world market of a product. Two of these regions (termed hereafter as "Countries 1 and 2" or "Players 1 and 2"), have adopted the GM technology and seek to determine their labeling regime (i.e., whether to label their GM and conventional produce or not). The third producing region represents the rest of the producing regions in the world (termed hereafter as "rest of the world" or "R.O.W."). To concentrate on the labeling decisions of countries that have adopted the GM technology, we assume that the R.O.W. has not adopted the new technology and supplies the world market with non-labeled conventional products.

As mentioned previously, the focus of our analysis is on the strategic interdependence between Countries 1 and 2 and its effect on the formulation of their labeling strategies.[1] This strategic interaction is modeled as a strategic game where the two GM producing countries determine their labeling regimes non-cooperatively. In particular, Countries 1 and 2 decide on whether to label their GM and conventional products or not independently but aware that their labeling strategies affect each other's payoffs. The objective of each GM producing region is to determine the labeling regime that maximizes the economic welfare of its

[1] Note that, while labeling has been the controversial focal point in the discussions on the regulation of products of biotechnology, it is certainly not the only factor affecting the development of global markets for GM crops and products. While not the focus of this paper, protection of intellectual property and the costs of regulatory approval are also endogenous to the various governments and can affect the market potential of agricultural biotechnology.

producers. Since all regions export their produce to the world market, maximizing producer welfare is equivalent to maximizing total economic surplus in these countries.

Note that, in addition to facilitating the analysis of the GM producing countries' strategic interaction in the world market, the assumption that the GM producing countries export their produce to the world market captures the large producing countries' reliance on global demand conditions. As will be shown later in the paper, while this assumption enhances the tractability of our analysis considerably, it does not affect the qualitative nature of our results.

Once the regulatory regimes have been determined, farmers in each producing region decide on which crop to grow and consumers make their purchasing decisions observing the types and prices of products supplied to the world market. Our analysis assumes fixed proportions between the farm output and the final consumer product.[2] To retain tractability, all processing and marketing costs other than segregation costs associated with a mandatory labeling regime are normalized to zero.

It is important to note that the labeling decision of a country affects the nature of its produce as well as the nature of products supplied to the world market. For instance, while the adoption of mandatory labeling results in the creation of two separate supply channels for GM and conventional products, the absence of a labeling requirement results in the GM and conventional products being marketed together as a non-labeled good. Table 1 shows the nature of the products supplied to the world market under the different combinations of labeling strategies of Countries 1 and 2.

As shown in Table 1, four distinct scenarios emerge:

Scenario 1: Countries 1 and 2 label their produce and two separate supply channels for GM and conventional products emerge. Note that, since all GM products are required to be labeled as such, non-labeled products supplied by the R.O.W. will be (correctly) perceived by consumers as being conventional (non-GM).

Scenario 2: No country labels its products. GM and conventional products are marketed together as a non-labeled good. Since GM products are credence goods (Darby and Karni, 1973), consumers cannot observe the (GM or conventional) nature of the product supplied.

[2] By assuming fixed proportions we implicitly assume that the GM technology does not change the technical relationship between the farm output and the final consumer product under concern. As pointed out by an anonymous reviewer, if the GM variety provided an advantage in pest resistance, storability or other post harvest losses, then there would be a systematic violation of the assumption of fixed proportions between the farm outputs and the final consumer product. The obvious reason is that, in such a case, there will be more final consumer product for a unit of farm output when this is GM relative to when it is conventional.

Scenario 3: Country 2 adopts mandatory labeling, while Country 1 does not label its products. Under this scenario, there are three products supplied to the market: the GM-labeled product, the non-labeled product, and the conventional-labeled product.

Scenario 4: Country 1 adopts mandatory labeling, while Country 2 does not label its products. The products supplied in this case are the same as those under Scenario 3.

TABLE 1. Products supplied under different labeling regimes

		Country 2	
		Labeling	**No Labeling**
Country 1	**Labeling**	*Scenario 1* GM-labeled product, Conventional (labeled and non-labeled) product	*Scenario 4* GM-labeled product, Conventional-labeled product, Non-labeled product
	No Labeling	*Scenario 3* GM-labeled product, Conventional-labeled product, Non-labeled product	*Scenario 2* Non-labeled product

As mentioned previously, the objective of each GM producing country is to determine the labeling regime that maximizes its domestic producer welfare. For a Nash equilibrium in labeling strategies to exist, the equilibrium labeling strategy of each country should be the best response to the other country's equilibrium labeling strategy. Put in a different way, a profile of labeling strategies is a Nash equilibrium, when no country has incentives to deviate, i.e., no country can enhance the welfare of its producers by changing its labeling policy. In this context, to evaluate the plausibility of the different scenarios in constituting a Nash equilibrium, we need to determine the welfare of each country's producers for each of the four scenarios identified above.

Note that, in each scenario, different actors pursuing different objectives are making different decisions. For instance, producers in each GM supplying country decide whether to grow GM crops or not, while consumers in the world market decide whether to buy these products or not. To capture the partial adoption of the GM technology in the major producing regions around the world (James, 2003), this paper explicitly accounts for producer heterogeneity in terms of the returns they receive from the different crops. Similarly, to capture the diversity in consumer attitudes toward the products of biotechnology expressed in survey and various stated consumer preference studies around the world, the study explicitly accounts for heterogeneous consumer preferences for GM and conventional products.

3. Production Decisions

This section analyzes farmer production decisions in the counties that have adopted the GM technology under the different scenarios on labeling regimes presented in Table 1. The models of producer heterogeneity developed here are similar in spirit to the models by Giannakas (2002) and Fulton and Giannakas (2004) that analyze production decisions under imperfect enforcement of intellectual property rights (IPRs), and different regulatory and labeling regimes for products of biotechnology, respectively, in the context of a country that has adopted the GM technology.

3.1 Production Decisions in Countries that Have Adopted the GM Technology

3.1.1 Mandatory Labeling: Production Decisions in Country i

As mentioned previously, producers in each producing region are assumed to differ in the net returns they receive from the different crops. Let $A \in [0, \text{A}]$ denote the attribute that differentiates producers. For tractability, producers are assumed to be uniformly distributed between 0 and A. Consider a farmer with differentiating attribute A in country i ($i \in \{1, 2\}$), that decides whether to produce the GM, the conventional or an alternative crop. Without loss of generality, farmers are assumed to produce one unit of output and the maximum per unit net returns to the production of the different crops are given by:[3]

[3] Note that, by assuming a unit production, we implicitly translate all differences between farmers into differences in the costs of producing the different crops. Similarly, by assuming unit production of both the conventional and the GM crop, we translate all benefits from the new technology into production cost savings. While such production cost savings have been the focus of the producer-oriented, first generation GM products similar to that modeled in this paper, there is no reason to believe that adopting the GM technology would leave the yields unaffected. Explicitly accounting for (positive or negative) yield effects, however, results in non-linearities that make the derivation of an analytical solution impossible (this point is also made in Fulton & Giannakas (2004), p.47). Before concluding this note, it should be pointed out that the model can also be seen as reflecting production decisions on units of output. In this case, farmers producing multiple units of output under variable returns to scale would be “located” at multiple points of the [0, A] interval.

$\pi^l_{gm} = P^S_{gm} - (\alpha_i A + w^l_{gmi})$ If a unit of the GM crop is produced

$\pi^l_t = P^S_t - (\beta_i A + w^l_{ti})$ If a unit of conventional crop is produced

$\pi_a = 0$ If a unit of alternative crop is produced

To save on notation, the net returns to the alternative crop are assumed to be constant among producers and equal to zero.[4] The parameters P^S_{gm} and P^S_t stand for the unit farm prices for the GM and conventional crops, respectively, with $P^S_{gm} < P^S_t$ (i.e., the conventional crop receives a premium over the GM crop). The parameters w^l_{gmi} and w^l_{ti} denote the base per unit costs associated with the production of the GM and conventional crops, respectively, under the labeling regime. The base costs of production are common to all producers and encompass such things as the cost of seeds and chemicals used, the costs associated with the segregation of the two crops under a labeling regime etc. To capture the producer orientation of the first generation of GM products and the fact that the majority of segregation costs are incurred in the conventional supply channel (Fulton and Giannakas, 2004), it is assumed that $w^l_{ti} > w^l_{gmi}$.

The parameters α_i and β_i are cost enhancement factors associated with the production of GM and conventional crops in Country *i*, respectively. Thus, the terms $\alpha_i A$ and $\beta_i A$ capture the producer heterogeneity in terms of the costs associated with the production of the two crops which stems from differences in location and quality of the land, education, experience, management skills etc. The total costs associated with the unit production of the GM and conventional crops for the producer with differentiating attribute A are then given by $\alpha_i A + w^l_{gmi}$ and $\beta_i A + w^l_{ti}$, respectively.

The partial adoption of GM crops indicates that, despite the producer orientation of the first generation of GM products, the new technology has been non-drastic in nature (i.e., many producers are still finding it optimal to grow conventional crops). To capture the observed coexistence of GM and conventional crops, the agronomic parameter α_i is assumed greater than β_i (see below). The difference $\alpha_i - \beta_i$ captures the cost effectiveness of the GM technology – the smaller is the difference $\alpha_i - \beta_i$, the more cost effective is the GM technology.

[4] This assumption is made for simplicity and does not affect the qualitative nature of our results.

A farmer's production decision is determined by the relative returns associated with the different crops. Figure 1 graphs π^l_{gm} and π^l_t and illustrates the farmer production decisions when the price and cost parameters are such that the GM technology is non-drastic and all crops enjoy positive production shares.

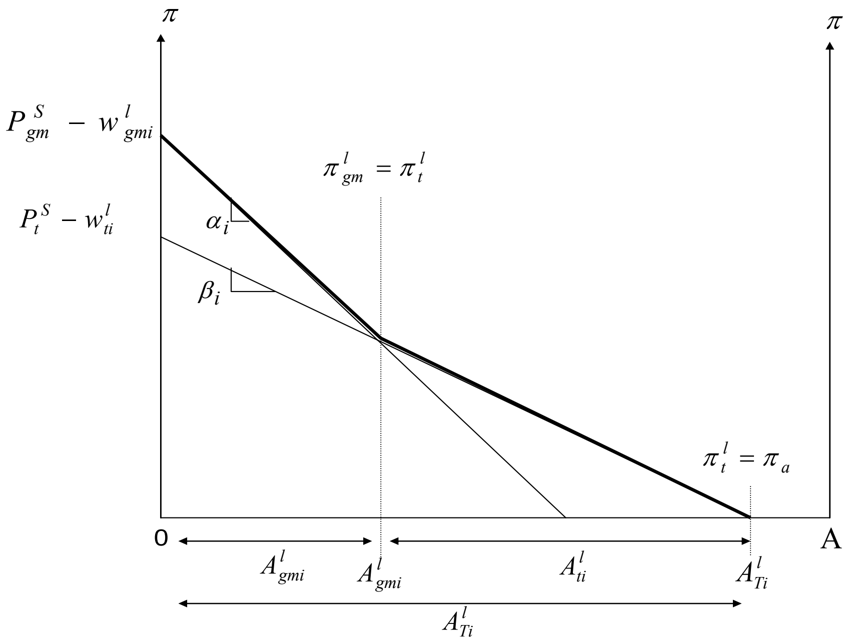

Figure 1: Production decisions and welfare under mandatory labeling

The farmer with differentiating attribute A^l_{gmi} (determined by the intersection of π^l_{gm} and π^l_t) is indifferent between producing the conventional and GM crops – the net returns associated with the production of these crops are the same. Farmers located to the left of A^l_{gmi} (i.e. producers with $A \in [0, A^l_{gmi})$) find it profitable to produce the GM crop. Since producers have been assumed to be uniformly distributed within 0 and A, A^l_{gmi} gives the quantity of the GM crop produced in Country i. Mathematically, A^l_{gmi} is given by:

$$A^l_{gmi} = \frac{P^S_{gm} - w^l_{gmi} - P^S_t + w^l_{ti}}{\alpha_i - \beta_i} \quad (1)$$

Similarly the farmer with differentiating attribute A_{Ti}^{l} is indifferent between producing the conventional and the alternative crops. A_{Ti}^{l} is determined by the intersection of the π_t^l and π_a curves in Figure 1, and gives the total quantity of the GM and conventional crops supplied by Country i as:

$$A_{Ti}^{l} = \frac{P_t^S - w_{ti}^l}{\beta_i} \tag{2}$$

The quantity of the conventional crop produced by Country i is then given by A_{Ti}^{l} - A_{gmi}^{l}, or:

$$A_{ti}^{l} = \frac{P_t^S - w_{ti}^l}{\beta_i} - \frac{P_{gm}^S - w_{gmi}^l - P_t^S + w_{ti}^l}{\alpha_i - \beta_i} \tag{3}$$

Analyzing equations (1)-(3) shows that if $P_{gm}^S - w_{gmi}^l \leq P_t^S - w_{ti}^l$ the adoption of the GM technology will be zero (i.e., the GM technology will be ineffective), while if $P_{gm}^S - w_{gmi}^l \geq (\alpha_i / \beta_i)(P_t^S - w_{ti}^l)$ all producers will adopt the GM technology (i.e., the GM technology will be drastic). To focus on the empirically relevant case of partial adoption of the GM technology (i.e., the case in which the GM technology is non-drastic), our analysis assumes that $P_t^S - w_{ti}^l < P_{gm}^S - w_{gmi}^l < (\alpha_i / \beta_i)(P_t^S - w_{ti}^l)$.

Aggregate producer welfare under the labeling regime is given by the area underneath the effective net returns curve (shown by the bold kinked line in Figure 1) and equals:

$$\Pi_i^l = \frac{(P_{gm}^S - w_{gmi}^l)A_{gmi}^l + (P_t^S - w_{ti}^l)A_{Ti}^l}{2} \tag{4}$$

3.1.2 No Labeling: Production Decisions in Country i

Under a no labeling regime, the farm price for GM and conventional crops is the same and the net returns function for a producer with differentiating attribute A becomes:

$\pi_{gm}^{nl} = P_{nl}^S - (\alpha_i A + w_{gmi}^{nl})$ If a unit of GM crop is produced

$\pi_t^{nl} = P_{nl}^S - (\beta_i A + w_{ti}^{nl})$ If a unit of conventional crop is produced

$\pi_a = 0$ If a unit of alternative crop is produced

where P_{nl}^S is the farm price when the GM and conventional crops are marketed together. The parameters w_{gmi}^{nl} and w_{ti}^{nl} are the per unit base costs of producing the GM and conventional crops, respectively, under a no labeling regime. It should be noted that the base costs of producing the two crops under no labeling are different than those under a labeling regime. An obvious reason for this difference is the absence of segregation and labeling costs when the two crops are marketed together as a non-labeled good. A second reason is the pricing of the new technology by the life science sector which, as shown by Giannakas (2002, p.490), depends on the labeling policy of the GM producing country.

The quantities of the different products supplied under a no labeling regime can be derived by setting $P_{gm}^S = P_t^S = P_{nl}^S$ in equations (1), (2) and (3) i.e.,

$$A_{gmi}^{nl} = \frac{w_{ti}^{nl} - w_{gmi}^{nl}}{\alpha_i - \beta_i} \tag{5}$$

$$A_{ti}^{nl} = \frac{P_{nl}^S - w_{ti}^{nl}}{\beta_i} - \frac{w_{ti}^{nl} - w_{gmi}^{nl}}{\alpha_i - \beta_i} \tag{6}$$

$$A_{nli}^{nl} = \frac{P_{nl}^S - w_{ti}^{nl}}{\beta_i} \tag{7}$$

Figure 2 graphs the net return functions and the quantities of the different crops under the no labeling regime. To allow for positive market shares of the two crops, we focus on the case where $P_{nl}^S - w_{ti}^{nl} < P_{nl}^S - w_{gmi}^{nl} < (\alpha_i / \beta_i)(P_{nl}^S - w_{ti}^{nl})$. Aggregate producer welfare in Country i under a no labeling regime is given by the area underneath the bold kinked curve in Figure 2 and equals:

$$\Pi_i^{nl} = \frac{(P_{nl}^S - w_{gmi}^{nl})A_{gmi}^{nl} + (P_{nl}^S - w_{ti}^{nl})A_{nli}^{nl}}{2} \tag{8}$$

3.2 Production Decisions in the Rest of the World

Since, by assumption, the R.O.W. has not adopted the GM technology, the production decision of its farmers is reduced to the choice between the conventional crop and its alternative. Given that the R.O.W. does not label its conventional product, the net returns function for a farmer with differentiating attribute A is given by:

$\pi_t = P_{nl}^S - (\beta_3 A + w_{t3})$ If a unit of conventional crop is produced

$\pi_a = 0$ If a unit of alternative crop is produced

Figure 3 depicts the determination of the quantity of non-labeled conventional crop supplied by the R.O.W. given by:

$$A_{nl3} = \frac{P_{nl}^S - w_{t3}}{\beta_3} \tag{9}$$

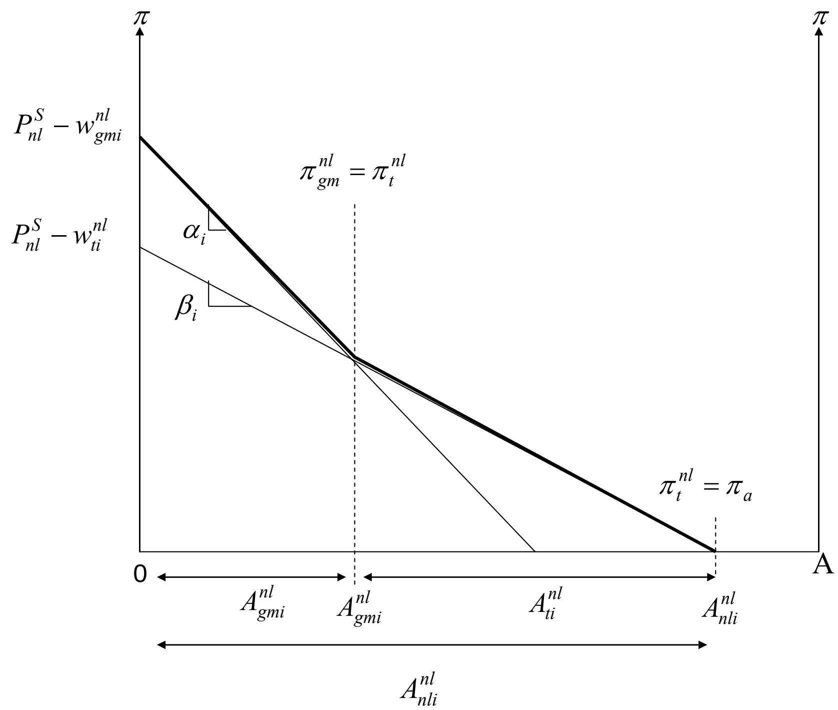

Figure 2: Production decisions and welfare under no labeling

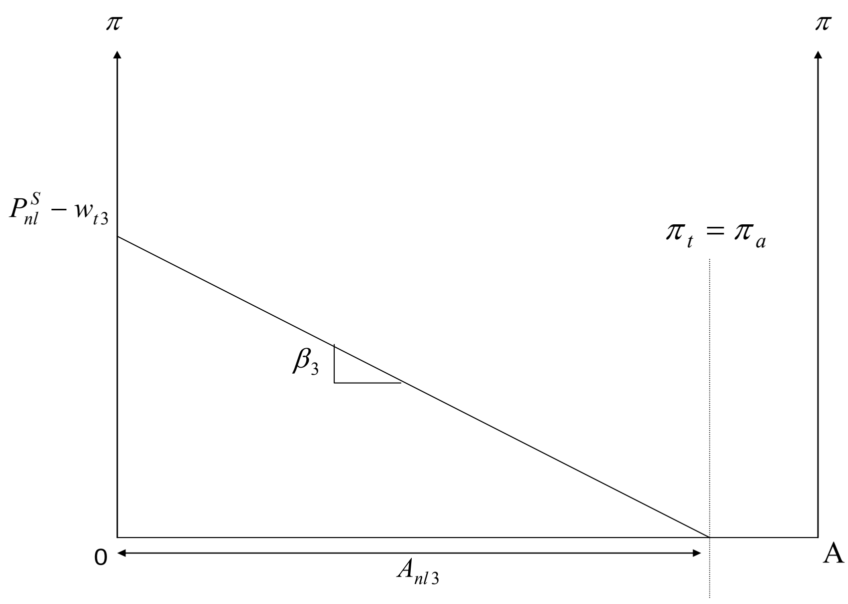

Figure 3: Production decisions in the Rest of the World

3.3 Determination of the World Supplies

The total world supply for each product under the different labeling scenarios outlined in Table 1 is derived through the summation of the relevant quantities supplied by each producing region. In Scenario 1, for instance, two separate supply channels for GM and conventional products emerge. Recall that, since all GM products are segregated and labeled as such, products supplied by the R.O.W. would be correctly perceived by consumers as being conventional (i.e., non-GM). In this context, the summation of the GM quantities supplied by Countries 1 and 2 gives the total supply of the GM product; while the summation of the conventional produce supplied by each region gives the total supply of the conventional product.[5]

The determination of aggregate supplies for the GM and conventional products under Scenario 1 is illustrated in Figure 4 where x represents output produced. The graphical and mathematical expressions for the total supplies under all four scenarios are presented below.

3.3.1 World Supplies under Scenario 1 (Both countries label their products)

GM Crop

$$P_{gm}^{S1} = aA_t^{S1} + (g+a)A_{gm}^{S1} + (b-h)w_{t1}^{l} + (c-i)w_{t2}^{l} + dw_{t3} + hw_{gm1}^{l1} + iw_{gm2}^{l1} \qquad (10)$$

Conventional Crop

$$P_t^{S1} = aA_t^{S1} + aA_{gm}^{S1} + bw_{t1}^{l} + cw_{t2}^{l} + dw_{t3} \qquad (11)$$

where $a = \beta_1\beta_2\beta_3/(\beta_1\beta_2 + \beta_2\beta_3 + \beta_1\beta_3)$

$b = \beta_2\beta_3/(\beta_1\beta_2 + \beta_2\beta_3 + \beta_1\beta_3)$

$c = \beta_1\beta_3/(\beta_1\beta_2 + \beta_2\beta_3 + \beta_1\beta_3)$

$d = \beta_1\beta_2/(\beta_1\beta_2 + \beta_2\beta_3 + \beta_1\beta_3)$

$g = (\alpha_1 - \beta_1)(\alpha_2 - \beta_2)/[(\alpha_1 - \beta_1) + (\alpha_2 - \beta_2)]$

$h = (\alpha_2 - \beta_2)/[(\alpha_1 - \beta_1) + (\alpha_2 - \beta_2)]$ and

$i = (\alpha_1 - \beta_1)/[(\alpha_1 - \beta_1) + (\alpha_2 - \beta_2)]$.

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[5] The total quantity of GM product supplied to the world market under Scenario 1 is given by $A_{gm}^{S1} = \sum_i A_{gmi}^{S1} = \sum_i \frac{P_{gm}^{S1} - w_{gmi}^{l} - P_t^{S1} + w_{ti}^{l}}{(\alpha_i - \beta_i)}$ while the total quantity of conventional product equals $A_t^{S1} = \sum_i A_{ti}^{S1} + A_{nl3}^{S1} = \sum_i \left(\frac{P_t^S - w_{ti}^l}{\beta_i} - \frac{P_{gm}^S - w_{gmi}^l - P_t^S + w_{ti}^l}{(\alpha_i - \beta_i)} \right) + \frac{P_t^{S1} - w_{t3}^{nl}}{\beta_3}$. Utilizing Cramer's rule we get the inverse total supplies for the GM and conventional products shown in equations (10) and (11).

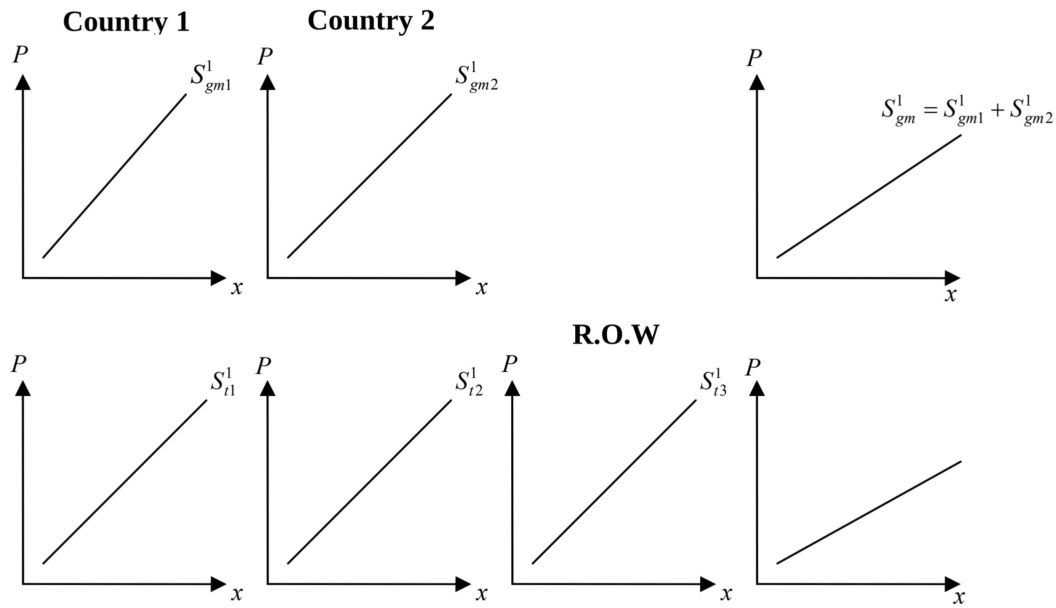

Figure 4: Determination of total supplies under Scenario 1

3.3.2 World Supply under Scenario 2 (No country labels its products)

In the absence of labeling, only one supply channel emerges (see Figure 5). The aggregate world supply of the non-labeled product is given by the summation of the quantities produced in the three regions as: [6]

$$P_{nl}^{S2} = aA_{nl}^{S2} + bw_{t1}^{nl} + cw_{t2}^{nl} + dw_{t3} \quad (12)$$

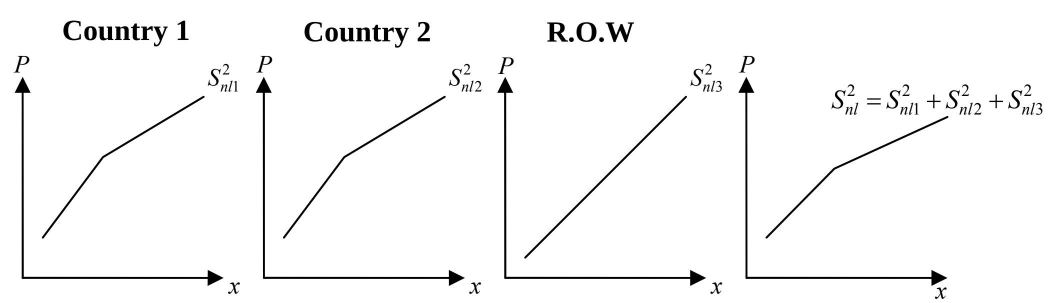

Figure 5: Determination of the total supply under Scenario 2

[6] The supply of the non-labeled product is kinked because it contains both GM and conventional products (see Fulton and Giannakas (2004)).

3.3.3 World Supplies under Scenarios 3 and 4 (One country labels its products)

In these scenarios, only one of the countries that have adopted the GM technology labels its products. When only Country 1(2) labels its products, the quantities of GM- and conventional-labeled products supplied by this country correspond to the world supplies of these products. The aggregate supply of the non-labeled product is then determined by the quantities produced by Country 2(1) and the R.O.W. in Scenario 4(3). Specifically, the world supplies under Scenarios 3 and 4 are:

GM Crop in Scenario 3

$$P_{gm}^{S3} = \beta_2 A_t^{S3} + \alpha_2 A_{gm}^{S3} + w_{gm2}^{l3} \tag{13}$$

Non-labeled Crop in Scenario 3

$$P_{nl}^{S3} = mA_{nl}^{S3} + nw_{t1}^{nl} + ow_{t3} \tag{14}$$

Conventional Crop in Scenario 3

$$P_t^{S3} = \beta_2 A_t^{S3} + \beta_2 A_{gm}^{S3} + w_{t2}^{l} \tag{15}$$

with $m = \beta_1\beta_3/(\beta_1 + \beta_3)$

$n = \beta_3/(\beta_1 + \beta_3)$ and

$o = \beta_1/(\beta_1 + \beta_3)$

GM Crop in Scenario 4

$$P_{gm}^{S4} = \beta_1 A_t^{S4} + \alpha_1 A_{gm}^{S4} + w_{gm1}^{l4} \tag{16}$$

Non-labeled Crop in Scenario 4

$$P_{nl}^{S4} = pA_{nl}^{S4} + qw_{t2}^{nl} + rw_{t3} \tag{17}$$

Conventional Crop in Scenario 4

$$P_t^{S4} = \beta_1 A_t^{S4} + \beta_1 A_{gm}^{S4} + w_{t1}^{l} \tag{18}$$

with $p = \beta_2\beta_3/(\beta_2 + \beta_3)$

$q = \beta_3/(\beta_2 + \beta_3)$ and

$r = \beta_2/(\beta_2 + \beta_3)$

Figure 6 depicts the determination of aggregate supplies under Scenario 4.

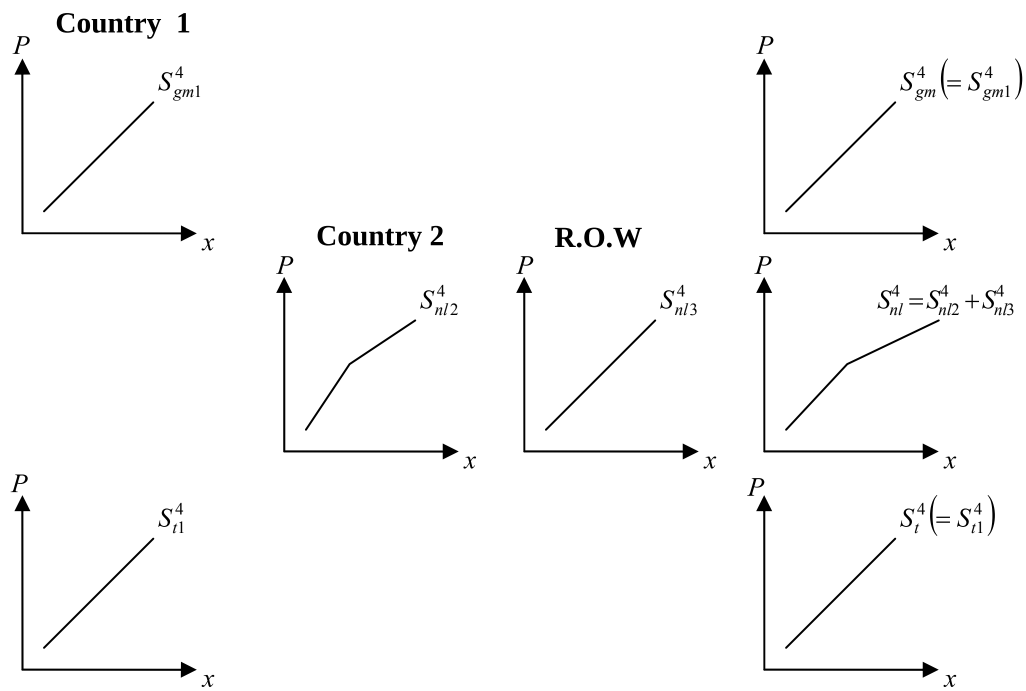

Figure 6: Determination of total supplies under Scenario 4

4. Consumption Decisions and Determination of Total Demands

This section focuses on consumer purchasing decisions under each of the scenarios presented in Table 1. To capture the GM producing countries' strategic interaction in the world market and the effect of global demand conditions on their optimal regulatory responses, a unique consuming region encompassing the world consumers is considered. The methodological framework utilized in the analysis of consumer behavior derives from the models of vertical product differentiation developed by Giannakas and Fulton (2002) and Fulton and Giannakas (2004). This framework of analysis allows for heterogeneous consumer preferences for GM and conventional products.

4.1 Consumption Decisions under Scenario 1 (Both countries label)

Let $c\in[0, C]$ be the attribute that differentiates consumers. The value of c differs according to consumer capturing the diversity in consumer attitudes towards GM and conventional products. For simplicity, consumers are assumed to be uniformly distributed between the polar values of c (i.e., 0 and C). Consider a consumer with differentiating attribute c. Assuming that this consumer buys one unit of either the GM, the conventional or a substitute product and that this purchase represents a small share of his total budget, his utility can be expressed as:

$U_{gm}^{S1} = U - P_{gm}^{D1} - \lambda c$ If a unit of GM product is consumed

$U_{t}^{S1} = U - P_{t}^{D1} - \mu c$ If a unit of conventional product is consumed

$U_{s} = U - P_{s}$ If a unit of a substitute product is consumed

where U is a per unit base level of utility associated with the consumption of a product and it is common to all consumers. The parameters P_{gm}^{D1}, P_{t}^{D1} and P_{s} denote the retail prices of the GM, the conventional and the substitute product, respectively. The parameters λ and μ are positive utility discount factors associated with the consumption of the GM and conventional products, respectively, so that the terms λc and μc represent the utility discount from the consumption of the GM and conventional products for the consumer with differentiating attribute c. To capture the expressed consumer opposition to GM products, we assume that $\lambda > \mu$ with the difference $\lambda - \mu$ reflecting the level of consumer aversion to GM products. To save on notation, we assume that consumers place the same value on the substitute product.[7]

A consumer's purchasing decision is determined by the relative utilities associated with the consumption of the different products. Note that, due to their vertical product differentiation, for both the GM and conventional products to enjoy positive consumer demands, the price of the substitute has to be greater than the price of the conventional product which, in turn, has to be greater than the price of the GM product. Thus, to allow for both GM and conventional products to enjoy positive market shares when Countries 1 and 2 label their products, we assume that $P_{s} > P_{t}^{D1} > P_{gm}^{D1}$. Figure 7 graphs U_{gm}^{S1}, U_{t}^{S1} and U_{s} and illustrates the consumer purchasing decisions for the case in which prices and preference parameters are such that all products enjoy positive shares of the market.

The consumer with differentiating attribute c_{gm}^{1} (determined by the intersection of U_{gm}^{S1} and U_{t}^{S1}) is indifferent between purchasing the conventional product and its GM counterpart – the utility associated with the consumption of these products is the same. Consumers located to the left of c_{gm}^{1} (i.e., consumers with differentiating attribute $c \in [0,\ c_{gm}^{1})$) prefer the GM product while consumers

[7] This assumption is made for simplicity and does not affect the qualitative nature of our results.

located to the right of c^1_{gm} buy either the conventional product (consumers with $c\in(c^1_{gm}, c^1_T])$ or the substitute product (consumers with $c\in(c^1_T, C])$.

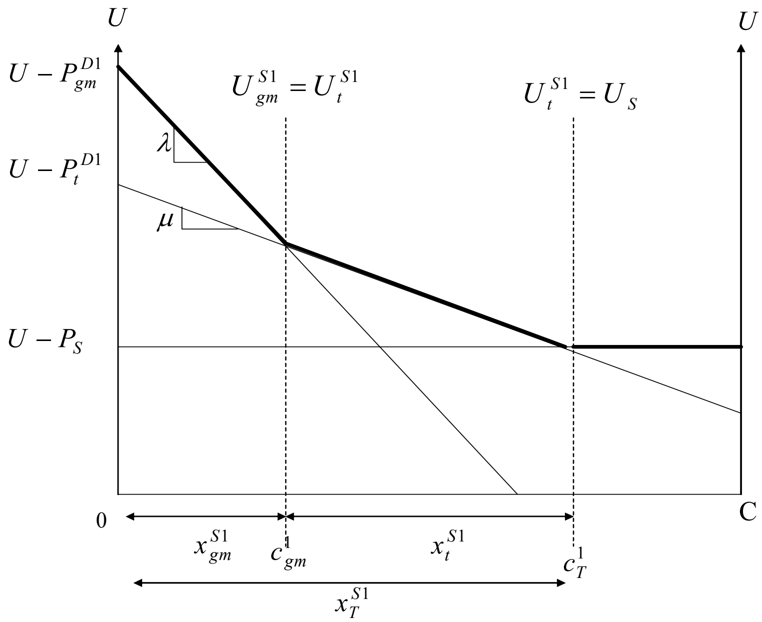

Figure 7: Consumption decisions under Scenario 1

When consumers are uniformly distributed between 0 and C, c^1_{gm} gives the quantity of the GM product consumed in the world market under Scenario 1, x^{S1}_{gm}. Therefore, the demand for the GM product is given by:

$$x^{S1}_{gm}=\frac{P^{D1}_t-P^{D1}_{gm}}{\lambda-\mu} \tag{19}$$

The total quantity of GM and conventional products demanded in the world market is given by:

$$x^{S1}_T=\frac{P_s-P^{D1}_t}{\mu} \tag{20}$$

while, subtracting x^{S1}_{gm} from x^{S1}_T gives the total demand for the conventional product as:

$$x_t^{S1} = \frac{P_s - P_t^{D1}}{\mu} - \frac{P_t^{D1} - P_{gm}^{D1}}{\lambda - \mu} \tag{21}$$

The inverse consumer demands for the GM and conventional products can then be written as:

$$P_{gm}^{D1} = P_s - \mu x_t^{S1} - \lambda x_{gm}^{S1} \tag{22}$$

$$P_t^{D1} = P_s - \mu x_t^{S1} - \mu x_{gm}^{S1} \tag{23}$$

4.2 Consumption Decisions under Scenario 2 (No country labels its products)

In this scenario, GM and conventional products are marketed together as a non-labeled good. Consumers have the choice between the non-labeled product and its substitute and the utility function becomes:

$E\left(U_{nl}^{S2}\right) = U - P_{nl}^{D2} - \phi c$ If a unit of non-labeled product is consumed

$U_s = U - P_s$ If a unit of the substitute product is consumed

where P_{nl}^{D2} is the retail price of the non-labeled product, and ϕ is the discount factor associated with its consumption. Due to the credence nature of the GM product, consumers cannot distinguish between the GM and conventional products. Since consumers are uncertain about the nature of the non-labeled product, its consumption is associated with an expected utility (Giannakas and Fulton, 2002).

Assuming that consumers have rational expectations, the utility derived from the consumption of the non-labeled product is proportional to the global rate of adoption of the GM product. The greater is the production share of the GM product, ψ, the greater is the perceived probability that the non-labeled product is genetically modified, and the lower is the utility associated with its consumption. The utility discount factor associated with the consumption of the non-labeled product, ϕ, is given by:

$$\phi = \psi\lambda + (1-\psi)\mu = \psi(\lambda - \mu) + \mu \tag{24}$$

where $\psi = A_{gm/nl}^{S2} \big/ A_{nl}^{S2}$ with $A_{gm/nl}^{S2}$ being the quantity of GM product supplied by all countries that do not label their products, and A_{nl}^{S2} being the total quantity of the non-labeled product (which includes the non-labeled production by the R.O.W.). The parameter ψ can be rewritten as:

$$\psi = \frac{e\left(w_{t1}^{nl} - w_{gm1}^{nl}\right) + f\left(w_{t2}^{nl} - w_{gm2}^{nl}\right)}{A_{nl}^{S2}} \text{ with } e = 1/(\alpha_1 - \beta_1) \text{ and } f = 1/(\alpha_2 - \beta_2) \tag{25}$$

Figure 8 graphs $E\left(U_{nl}^{S2}\right)$ and U_s as well as the determination of the consumer demand for the non-labeled product, x_{nl}^{S2}, when $P_s > P_{nl}^{D2}$. Formally, x_{nl}^{S2} is given by:

$$x_{nl}^{S2} = \frac{P_s - P_{nl}^{D2}}{\psi(\lambda - \mu) + \mu} \tag{26}$$

and its inverse form can be written as:

$$P_{nl}^{D2} = P_s - (\lambda - \mu)\psi x_{nl}^{S2} - \mu x_{nl}^{S2} \tag{27}$$

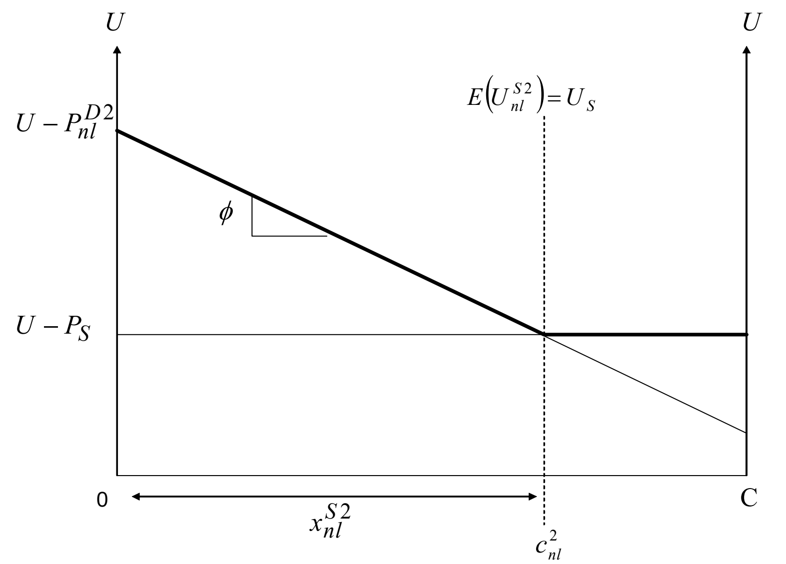

Figure 8: Consumption decisions under Scenario 2

Note that, in the absence of labeling, the global production share of the GM product affects the consumer demand – the consumer demand in the absence of labels is directly related to the supply conditions in the market. The greater is the global rate of adoption of the new technology, the lower is the market demand for the non-labeled product (on this issue see also Giannakas and Fulton (2002) and Fulton and Giannakas (2004)).

4.3 Consumption Decisions under Scenarios 3 and 4 (One country labels)

Under Scenarios 3 and 4 there are four products in the market and the consumer utility becomes:

$U_{gm}^{Si} = U - P_{gm}^{Di} - \lambda c$ If a unit of GM product is consumed

$E(U_{nl}^{Si}) = U - P_{nl}^{Di} - \phi' c$ If a unit of non-labeled product is consumed

$U_{t}^{Si} = U - P_{t}^{Di} - \mu c$ If a unit of conventional product is consumed

$U_{s} = U - P_{s}$ If a unit of the substitute product is consumed

with $i \in \{3,4\}$ indicating the relevant Scenario and $\phi' \neq \phi$ because $\psi' \neq \psi$. Figure 9 graphs U_{gm}^{Si}, $E(U_{nl}^{Si})$, U_{t}^{Si}, and U_s when $P_s > P_t^{Di} > P_{nl}^{Di} > P_{gm}^{Di}$ and the preference parameters are such that all products enjoy positive shares of the market.[8]

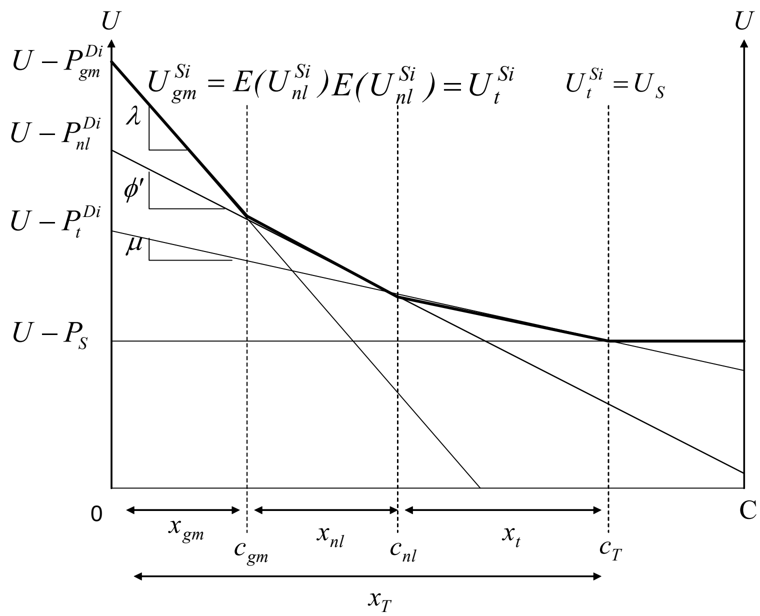

Figure 9: Consumption decisions under Scenarios 3 and 4

Note that the global production share of the GM product differs under Scenarios 3 and 4 since the country not labeling its produce is different in each case. For instance, when only Country 2 labels its products (Scenario 3), ψ_3 is given by:

[8] Note that if the price of the non-labeled product were less than the price of the GM-labeled product, the U_{nl} curve in Figure 9 would lie above the U_{gm} curve $\forall c$, and the GM product would be driven out of the market.

$$\psi_3 = \left(\frac{w_{t1}^{nl} - w_{gm1}^{nl}}{\alpha_1 - \beta_1} \right) \frac{1}{A_{nl}^{S3}} = \frac{A_{gm1}^{S3}}{A_{nl}^{S3}} \tag{28}$$

while when only Country 1 labels its products (Scenario 4), ψ becomes:

$$\psi_4 = \left(\frac{w_{t2}^{nl} - w_{gm2}^{nl}}{\alpha_2 - \beta_2} \right) \frac{1}{A_{nl}^{S4}} = \frac{A_{gm2}^{S4}}{A_{nl}^{S4}} \tag{29}$$

The consumer demands for the different products when only one country labels its produce are:

$$x_{gm}^{Si} = \frac{P_{nl}^{Di} - P_{gm}^{Di}}{(1-\psi)(\lambda - \mu)} \tag{30}$$

$$x_{nl}^{Si} = \frac{P_t^{Di} - P_{nl}^{Di}}{\psi(\lambda - \mu)} - \frac{P_{nl}^{Di} - P_{gm}^{Di}}{(1-\psi)(\lambda - \mu)} \tag{31}$$

$$x_t^{Si} = \frac{P_s - P_t^{Di}}{\mu} - \frac{P_t^{Di} - P_{nl}^{Di}}{\psi(\lambda - \mu)} \tag{32}$$

The inverse form of these demands is then:

$$P_{gm}^{Di} = P_s - \mu x_t^{Si} - [\mu + \psi(\lambda - \mu)] x_{nl}^{Si} - \lambda x_{gm}^{Si} \tag{33}$$

$$P_{nl}^{Di} = P_s - \mu x_t^{Si} - [\mu + \psi(\lambda - \mu)] x_{nl}^{Si} - [\mu + \psi(\lambda - \mu)] x_{gm}^{Si} \tag{34}$$

$$P_t^{Di} = P_s - \mu x_t^{Si} - \mu x_{nl}^{Si} - \mu x_{gm}^{Si} \tag{35}$$

The relevant expressions for the demands under Scenario 3(4) can be obtained by substituting $\psi_3(\psi_4)$ for ψ in equations (30)-(35).

5. Market Outcomes under the Different Labeling Scenarios

In this section the market outcomes for the four scenarios are established based on the results derived previously. Utilizing the supply and demand expressions derived in the previous two sections, a simple, stylized four-region trade model is developed for each scenario. The equilibrium conditions determine the prices and quantities of the relevant products as well as the welfare of the groups involved.

5.1 Market Outcomes under Scenario 1

Figure 10 depicts the configuration of the world market under Scenario 1 when the trading sector is perfectly competitive and trading costs are normalized to zero.[9] In this case, two distinct supply channels provide GM and conventional products to consumers in the world market and the prices paid by consumers are equal to those received by farmers, i.e.,

$$P_{gm}^{D1} = P_{gm}^{S1} \tag{36}$$

$$P_t^{D1} = P_t^{S1} \tag{37}$$

The market clearing condition implies that:

$$A_{gm}^{S1} = x_{gm}^{S1} = x_{gm}^{e1} \tag{38}$$

$$A_t^{S1} = x_t^{S1} = x_t^{e1} \tag{39}$$

where x_{gm}^{e1} and x_t^{e1} are the equilibrium quantities of GM and conventional products traded in the world market, respectively.

Substituting the expressions for the inverse demands (equations (22) and (23)) and supplies (equations (10) and (11)) for the relevant parameters in equations (36) and (37), and solving the system of equations we get the equilibrium quantities in the markets for GM and conventional products as:

$$x_{gm}^{e1} = \frac{h}{g+\lambda-\mu} w_{t1}^{l} - \frac{h}{g+\lambda-\mu} w_{gm1}^{l1} + \frac{i}{g+\lambda-\mu} w_{t2}^{l} - \frac{i}{g+\lambda-\mu} w_{gm2}^{l1} \tag{40}$$

$$\begin{aligned} x_t^{e1} = {} & \frac{1}{\mu+a} P_s - \left(\frac{b}{\mu+a} + \frac{h}{g+\lambda-\mu} \right) w_{t1}^{l} - \left(\frac{c}{\mu+a} + \frac{i}{g+\lambda-\mu} \right) w_{t2}^{l} - \frac{d}{\mu+a} w_{t3} \\ & + \frac{h}{g+\lambda-\mu} w_{gm1}^{l1} + \frac{i}{g+\lambda-\mu} w_{gm2}^{l1} \end{aligned} \tag{41}$$

Substituting equations (40) and (41) into the expressions for farm prices in equation (10) and (11), we get the equilibrium farm prices as:

$$P_{gm}^{S1*} = a x_t^{e1} + (g+a) x_{gm}^{e1} + (b-h) w_{t1}^{l} + (c-i) w_{t2}^{l} + d w_{t3} + h w_{gm1}^{l1} + i w_{gm2}^{l1} \tag{42}$$

$$P_t^{S1*} = a x_t^{e1} + a x_{gm}^{e1} + b w_{t1}^{l} + c w_{t2}^{l} + d w_{t3} \tag{43}$$

The aggregate producer welfare in Country i under Scenario 1 can be expressed as:

$$\Pi_i^{l1} = \frac{\left(P_{gm}^{S1*} - w_{gmi}^{l1}\right) x_{gmi}^{e1} + \left(P_t^{S1*} - w_{ti}^{l}\right) x_{Ti}^{e1}}{2} \tag{44}$$

---

[9] Note that both the trading costs and the market power of trading firms can be safely assumed away from our analysis since they affect the trade of both the conventional and GM products (whether these are labeled or not) leaving the qualitative nature of our results on the factors affecting the GM producing countries' labeling decisions unaffected. For an analysis of the labeling decisions under an imperfectly competitive trading sector see Veyssiere (2004).

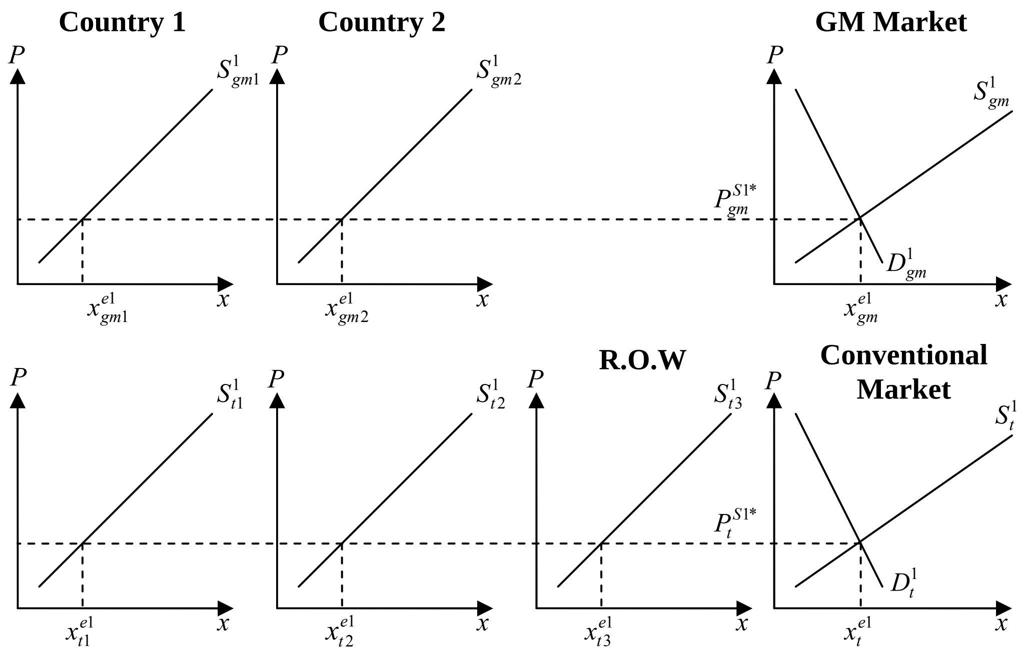

Figure 10: Market outcomes under Scenario 1

5.2 Market Outcomes under Scenario 2

Figure 11 depicts the configuration of the world market under Scenario 2. Since no country labels its products in this case, there is only one supply channel and the market clearing condition implies that:

$$A_{nl}^{S2} = x_{nl}^{S2} = x_{nl}^{e2} \tag{45}$$

where x_{nl}^{e2} is the equilibrium quantity of non-labeled product traded in the world market. Following the same procedure outlined in the previous section, the equilibrium quantity is given by:

$$x_{nl}^{e2} = \frac{1}{\mu + a} P_s - \frac{\lambda - \mu}{\mu + a} A_{gm/nl}^{S2} - \frac{b}{\mu + a} w_{t1}^{nl} - \frac{c}{\mu + a} w_{t2}^{nl} - \frac{d}{\mu + a} w_{t3} \tag{46}$$

The equilibrium price of the non-labeled product and producer welfare in Country i are then:

$$P_{nl}^{S2*} = a x_{nl}^{e2} + b w_{t1}^{nl} + c w_{t2}^{nl} + d w_{t3} \tag{47}$$

$$\Pi_i^{nl2} = \frac{\left(P_{nl}^{S2*} - w_{gmi}^{nl}\right) x_{gmi}^{e2} + \left(P_{nl}^{S2*} - w_{ti}^{nl}\right) x_{nli}^{e2}}{2} \tag{48}$$

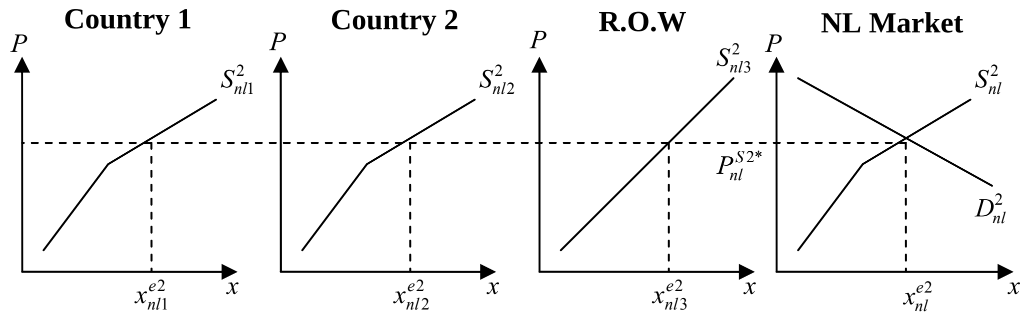

Figure 11: Market outcomes under Scenario 2

5.3 Market Outcomes under Scenarios 3 and 4

Figure 12 depicts the case in which only Country 1 labels its products (i.e., Scenario 4). As shown in this Figure, this scenario involves the emergence of three distinct supply channels: one for the GM, one for the conventional, and one for the non-labeled products. The market clearing conditions imply that:

$$x_{gm}^{S4} = A_{gm}^{S4} = x_{gm}^{e4} \tag{49}$$

$$x_{nl}^{S4} = A_{nl}^{S4} = x_{nl}^{e4} \tag{50}$$

$$x_{t}^{S4} = A_{t}^{S4} = x_{t}^{e4} \tag{51}$$

Following the same procedure established previously, we derive the equilibrium quantities of the three products as:

$$x_{gm}^{e4} = \frac{1}{\lambda-\mu+\alpha_1-\beta_1} w_{t1}^{l} - \frac{1}{\lambda-\mu+\alpha_1-\beta_1} w_{gm1}^{l4} - \frac{\lambda-\mu}{\lambda-\mu+\alpha_1-\beta_1} A_{gm2}^{S4} \tag{52}$$

$$x_{nl}^{e4} = \frac{Y+\sqrt{(Y)^2-4XZ}}{2X} \tag{53}$$

$$\begin{aligned} x_{t}^{e4} &= \frac{1}{\mu+\beta_1} P_s - \left(\frac{1}{\mu+\beta_1} + \frac{1}{\lambda-\mu+\alpha_1-\beta_1}\right) w_{t1}^{l} + \frac{1}{\lambda-\mu+\alpha_1-\beta_1} w_{gm1}^{l4} \\ &\quad + \frac{\lambda-\mu}{\lambda-\mu+\alpha_1-\beta_1} A_{gm2}^{S4} - \frac{\mu}{\mu+\beta_1} x_{nl}^{e4} \end{aligned} \tag{54}$$

where $X = p + \mu\beta_1/(\mu+\beta_1)$

$Y = \beta_1 P_s/(\mu+\beta_1) + \mu w_{t1}^{l}/(\mu+\beta_1) - q w_{t2}^{nl} - r w_{t3} - (\lambda-\mu) A_{gm2}^{S4}$ and

$Z = (\lambda-\mu) x_{gm}^{e4} A_{gm2}^{S4}$.

The farm prices of the three products are then:

$$P_{gm}^{S4*} = \beta_1 x_t^{e4} + \alpha_1 x_{gm}^{e4} + w_{gm1}^{l4} \tag{55}$$

$$P_{nl}^{S4*} = p x_{nl}^{e4} + q w_{t2}^{nl} + r w_{t3} \tag{56}$$

$$P_t^{S4*} = \beta_1 x_t^{e4} + \beta_1 x_{gm}^{e4} + w_{t1}^{l} \tag{57}$$

and aggregate producer welfare in Countries 1 and 2 is given by:

$$\Pi_1^{l4} = \frac{\left(P_{gm}^{S4*} - w_{gm1}^{l4}\right)x_{gm1}^{e4} + \left(P_t^{S4*} - w_{t1}^{l}\right)x_{T1}^{e4}}{2} \tag{58}$$

$$\Pi_2^{nl4} = \frac{\left(P_{nl}^{S4*} - w_{gm2}^{nl}\right)x_{gm2}^{e4} + \left(P_{nl}^{S4*} - w_{t2}^{nl}\right)x_{nl2}^{e4}}{2} \tag{59}$$

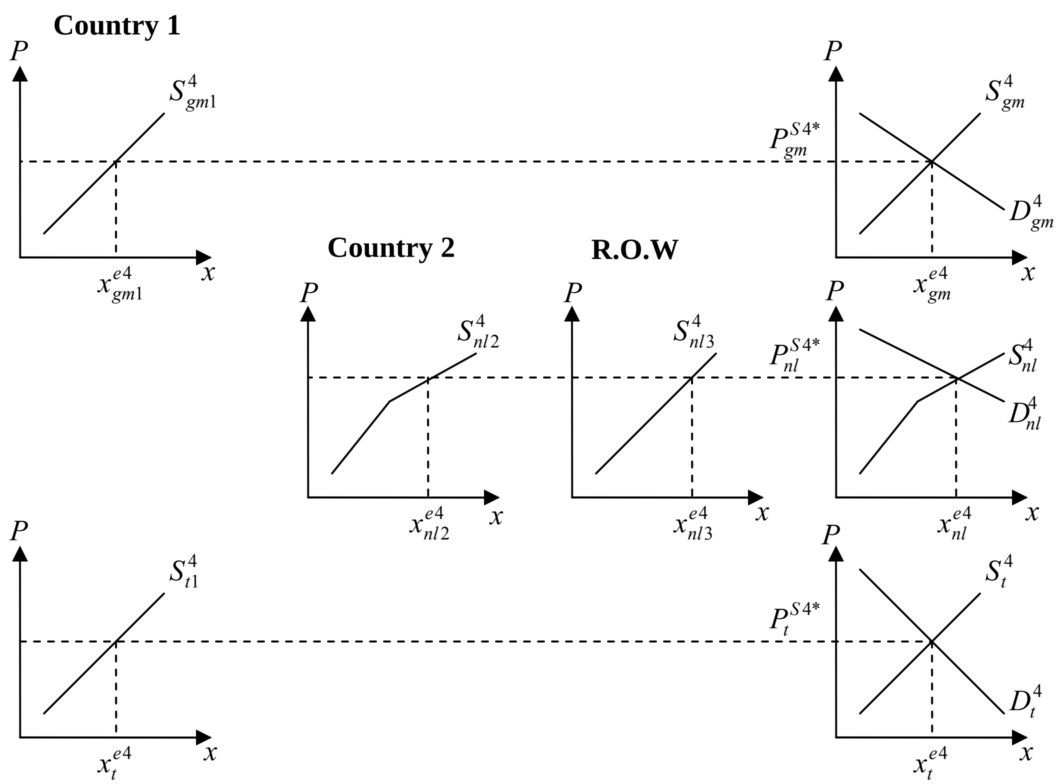

Figure 12: Market outcomes under Scenario 4

Following the same process we can get the equilibrium quantities and prices under Scenario 3 as:

$$x_{gm}^{e3} = \frac{1}{\lambda - \mu + \alpha_2 - \beta_2} w_{t2}^{l} - \frac{1}{\lambda - \mu + \alpha_2 - \beta_2} w_{gm2}^{l3} - \frac{\lambda - \mu}{\lambda - \mu + \alpha_2 - \beta_2} A_{gm1}^{S3} \quad (60)$$

$$x_{nl}^{e3} = \frac{Y_1 + \sqrt{(Y_1)^2 - 4X_1 Z_1}}{2X_1} \quad (61)$$

$$x_t^{e3} = \frac{1}{\mu + \beta_2} P_s - \left(\frac{1}{\mu + \beta_2} + \frac{1}{\lambda - \mu + \alpha_2 - \beta_2} \right) w_{t2}^{l} + \frac{1}{\lambda - \mu + \alpha_2 - \beta_2} w_{gm2}^{l3} + \frac{(\lambda - \mu)}{\lambda - \mu + \alpha_2 - \beta_2} A_{gm1}^{S3} - \frac{\mu}{\mu + \beta_2} x_{nl}^{e3} \quad (62)$$

with $X_1 = m + \mu\beta_2 / (\mu + \beta_2)$

$Y_1 = \beta_2 P_s / (\mu + \beta_2) + \mu w_{t2}^{l} / (\mu + \beta_2) - n w_{t1}^{nl} - o w_{t3} - (\lambda - \mu) A_{gm1}^{S3}$ and

$Z_1 = (\lambda - \mu) A_{gm1}^{S3} x_{gm}^{e3}$

$$P_{gm}^{S3*} = \beta_2 x_t^{e3} + \alpha_2 x_{gm}^{e3} + w_{gm2}^{l3} \quad (63)$$

$$P_{nl}^{S3*} = m x_{nl}^{e3} + n w_{t1}^{nl} + o w_{t3} \quad (64)$$

$$P_t^{S3*} = \beta_2 x_t^{e3} + \beta_2 x_{gm}^{e3} + w_{t2}^{l} \quad (65)$$

Aggregate producer welfare in Countries 1 and 2 then equals:

$$\Pi_1^{nl3} = \frac{\left(P_{nl}^{S3*} - w_{gm1}^{nl}\right) x_{gm1}^{e3} + \left(P_{nl}^{S3*} - w_{t1}^{nl}\right) x_{nl1}^{e3}}{2} \quad (66)$$

$$\Pi_2^{l3} = \frac{\left(P_{gm}^{S3*} - w_{gm2}^{l3}\right) x_{gm2}^{e3} + \left(P_t^{S3*} - w_{t2}^{l}\right) x_{T2}^{e3}}{2} \quad (67)$$

6. Determinants of the Nash Equilibrium in Labeling Strategies

This section focuses on establishing the conditions under which the different labeling scenarios examined previously can constitute a Nash equilibrium in labeling strategies. After having determined the aggregate producer welfare in each country under the different labeling scenarios,[10] we can formulate the payoff matrix for Countries 1 and 2, as:

[10] As pointed out by an anonymous reviewer, if the trading firms were able to exercise market power and were located in one of the GM producing countries, their profits would be part of the economic welfare of this country and should be included in the relevant payoffs depicted in Table 2. Obviously, the greater the weight placed by the regulator on the trading firms and/or the greater the imperfectly competitive trading firms' profits under a particular labeling regime, the greater the likelihood that this labeling regime would constitute the optimal policy response of the government in question.

TABLE 2. Payoff matrix

	Country 2: **Labeling**	Country 2: **No Labeling**
Country 1: Labeling	*Scenario 1* $\Pi_1^{l1} = \frac{\left(P_{gm}^{S1*} - w_{gm1}^{l1}\right)x_{gm1}^{e1} + \left(P_t^{S1*} - w_{t1}^{l}\right)x_{T1}^{e1}}{2}$; $\Pi_2^{l1} = \frac{\left(P_{gm}^{S1*} - w_{gm2}^{l1}\right)x_{gm2}^{e1} + \left(P_t^{S1*} - w_{t2}^{l}\right)x_{T2}^{e1}}{2}$	*Scenario 4* $\Pi_1^{l4} = \frac{\left(P_{gm}^{S4*} - w_{gm1}^{l4}\right)x_{gm1}^{e4} + \left(P_t^{S4*} - w_{t1}^{l}\right)x_{T1}^{e4}}{2}$; $\Pi_2^{nl4} = \frac{\left(P_{nl}^{S4*} - w_{gm2}^{nl}\right)x_{gm2}^{e4} + \left(P_{nl}^{S4*} - w_{t2}^{nl}\right)x_{nl2}^{e4}}{2}$
Country 1: No Labeling	*Scenario 3* $\Pi_1^{nl3} = \frac{\left(P_{nl}^{S3*} - w_{gm1}^{nl}\right)x_{gm1}^{e3} + \left(P_{nl}^{S3*} - w_{t1}^{nl}\right)x_{nl1}^{e3}}{2}$; $\Pi_2^{l3} = \frac{\left(P_{gm}^{S3*} - w_{gm2}^{l3}\right)x_{gm2}^{e3} + \left(P_t^{S3*} - w_{t2}^{l}\right)x_{T2}^{e3}}{2}$	*Scenario 2* $\Pi_1^{nl2} = \frac{\left(P_{nl}^{S2*} - w_{gm1}^{nl}\right)x_{gm1}^{e2} + \left(P_{nl}^{S2*} - w_{t1}^{nl}\right)x_{nl1}^{e2}}{2}$; $\Pi_2^{nl2} = \frac{\left(P_{nl}^{S2*} - w_{gm2}^{nl}\right)x_{gm2}^{e2} + \left(P_{nl}^{S2*} - w_{t2}^{nl}\right)x_{nl2}^{e2}}{2}$

6.1 Conditions for Scenario 1 being a Nash Equilibrium

For Scenario 1 to be a Nash equilibrium, no player should have an incentive to deviate from the labeling strategy when the other country has chosen to label its products. For labeling to be a country's best response to the other country's decision to label its products, the following inequalities have to hold:

$$\Pi_1^{l1} > \Pi_1^{nl3} \Leftrightarrow \Delta_1 = \Pi_1^{l1} - \Pi_1^{nl3} > 0 \Leftrightarrow$$
$$\Leftrightarrow \left(P_{gm}^{S1*} - w_{gm1}^{l1}\right)x_{gm1}^{e1} + \left(P_t^{S1*} - w_{t1}^{l}\right)x_{T1}^{e1} - \left[\left(P_{nl}^{S3*} - w_{gm1}^{nl}\right)x_{gm1}^{e3} + \left(P_{nl}^{S3*} - w_{t1}^{nl}\right)x_{nl1}^{e3}\right] > 0 \tag{68}$$

$$\Pi_2^{l1} > \Pi_2^{nl4} \Leftrightarrow \Delta_2 = \Pi_2^{l1} - \Pi_2^{nl4} > 0 \Leftrightarrow$$
$$\Leftrightarrow \left(P_{gm}^{S1*} - w_{gm2}^{l1}\right)x_{gm2}^{e1} + \left(P_t^{S1*} - w_{t2}^{l}\right)x_{T2}^{e1} - \left[\left(P_{nl}^{S4*} - w_{gm2}^{nl}\right)x_{gm2}^{e4} + \left(P_{nl}^{S4*} - w_{t2}^{nl}\right)x_{nl2}^{e4}\right] > 0 \tag{69}$$

6.2 Conditions for Scenario 2 being a Nash Equilibrium

For Scenario 2 to be a Nash equilibrium, no country should have incentive to adopt a labeling regime when the other country has chosen not to label its products. For no labeling to be a country's best response to the other country's decision to not label its products, the following inequalities have to hold:

$$\Pi_1^{nl2} > \Pi_1^{l4} \Leftrightarrow \Delta_3 = \Pi_1^{nl2} - \Pi_1^{l4} > 0 \Leftrightarrow$$
$$\Leftrightarrow \left(P_{nl}^{S2*} - w_{gm1}^{nl}\right)x_{gm1}^{e2} + \left(P_{nl}^{S2*} - w_{t1}^{nl}\right)x_{nl1}^{e2} - \left[\left(P_{gm}^{S4*} - w_{gm1}^{l4}\right)x_{gm1}^{e4} + \left(P_t^{S4*} - w_{t1}^{l}\right)x_{T1}^{e4}\right] > 0 \tag{70}$$

$$\Pi_2^{nl2} > \Pi_2^{l3} \Leftrightarrow \Delta_4 = \Pi_2^{nl2} - \Pi_2^{l3} > 0 \Leftrightarrow$$
$$\Leftrightarrow \left(P_{nl}^{S2*} - w_{gm2}^{nl}\right)x_{gm2}^{e2} + \left(P_{nl}^{S2*} - w_{t2}^{nl}\right)x_{nl2}^{e2} - \left[\left(P_{gm}^{S3*} - w_{gm2}^{l3}\right)x_{gm2}^{e3} + \left(P_{t}^{S3*} - w_{t2}^{l}\right)x_{T2}^{e3}\right] > 0 \quad (71)$$

6.3 Conditions for Scenario 3 being a Nash Equilibrium

Scenario 3 will be a Nash equilibrium when the following inequalities hold:

$$\Pi_1^{nl3} > \Pi_1^{l1} \Leftrightarrow \Delta_1 < 0 \quad (72)$$

$$\Pi_2^{l3} > \Pi_2^{nl2} \Leftrightarrow \Delta_4 < 0 \quad (73)$$

6.4 Conditions for Scenario 4 being a Nash Equilibrium

Finally, the conditions that result in Scenario 4 being a Nash equilibrium are:

$$\Pi_1^{l4} > \Pi_1^{nl2} \Leftrightarrow \Delta_3 < 0 \quad (74)$$

$$\Pi_2^{nl4} > \Pi_2^{l1} \Leftrightarrow \Delta_2 < 0 \quad (75)$$

6.5 Determinants of the Nash Equilibrium in Labeling Strategies: Discussion

The conditions presented above indicate that the Nash equilibrium configuration of labeling regimes in the countries that have adopted the GM technology depends on the relative farm prices for the GM, the conventional, and the non-labeled products under the different labeling scenarios, as well as on the cost of production under the GM and conventional technologies. The relative farm prices and costs of production are affected, in turn, by (i) the distribution of consumer preferences and the level of consumer aversion to GM products; (ii) the size of the segregation and labeling costs in the two countries; (iii) the relative productive efficiency and the cost effectiveness of the GM technology; (iv) the market power of the life science companies; and (v) the strength of intellectual property rights in these countries.

While it is certainly the interaction of all these parameters that determines whether a profile of labeling strategies will be a Nash equilibrium or not, the rest of this section will focus on separating the effect of each parameter on the potential of the different labeling scenarios to constitute a Nash equilibrium.[11] In so doing, we are able to gain insights on the general environment in which each labeling configuration is likely to emerge as a Nash equilibrium.

[11] A simple numerical example that illustrates (i) the emergence of the different labeling scenarios as a Nash equilibrium under the conditions identified in this paper, and (ii) the effect of the key parameters on Δ_1, Δ_2, Δ_3 and Δ_4 (and, thus, the effect of these parameters on the likelihood of the different labeling strategy profiles to constitute a Nash equilibrium) is available from the authors upon request.

Consumer aversion to GM products

Consistent with *a priori* expectations, expressions Δ_1 and Δ_2 in equations (68) and (69) rise with an increase in the level of consumer aversion to GM products (i.e., $\partial\Delta_1/\partial(\lambda-\mu)>0$ and $\partial\Delta_2/\partial(\lambda-\mu)>0$), indicating that the greater is the consumer opposition to GM products, the more likely it is that countries will find it optimal to label their products. Note that, in the presence of non-labeled products in the market (as is the case in Scenarios 2, 3 and 4), an increase in consumer aversion reduces the demand for these products and causes producer welfare to fall. When GM products are segregated and labeled as such, the rise in consumer aversion reduces the demand for GM products while increasing the demand for their conventional counterparts. When consumer aversion is high, all consumers prefer the conventional product, and the GM (and non-labeled) products are driven out of the market. The producer welfare gains from the increased demand for conventional products make the labeling regime appealing to countries when the consumer aversion is high.

On the other hand, a low level of consumer aversion to GM products reduces the appeal of labels and makes a non-labeling strategy more attractive. The lower is the consumer aversion to GM products, the greater are Δ_3 and Δ_4 (i.e., $\partial\Delta_3/\partial(\lambda-\mu)<0$ and $\partial\Delta_4/\partial(\lambda-\mu)<0$), and the greater is the likelihood that countries will find it optimal to not label their products.

Segregation and labeling costs

It can be shown that expressions Δ_1 and Δ_2 fall with an increase in the segregation costs associated with a labeling regime indicating that the lower are these costs, the more likely is that countries will find it optimal to label their products. Thus, Scenario 1 is more likely to be a Nash equilibrium when the segregation and labeling costs are relatively low in both countries.

When these costs are relatively high in both countries, the appeal of a non-labeling strategy increases and so does the likelihood that both countries will find it optimal to not label their products. Formally, the greater are the segregation and labeling costs, the greater are Δ_3 and Δ_4 in equations (70) and (71), and the more likely it is that Scenario 2 will emerge as the Nash equilibrium in labeling regimes.

Finally, a discrepancy in the segregation and labeling costs between the two countries might result in different regulatory responses to products of biotechnology. The greater is the difference in segregation and labeling costs between the two countries, the more likely it is that these countries will choose different labeling regimes (with the low cost country labeling its products and the high cost country opting for a no labeling regime).

Market power of the life science sector and strength of IPRs

Both the market power by the life science sector and the strength of its IPRs affect the base cost of producing the GM crop, w_{gm}. The greater is the market power of the life science sector and/or the stronger is the enforcement of its IPRs, the more expensive is the GM technology (Giannakas, 2002). It can then be shown that Δ_1 and Δ_2 increase with a reduction in w_{gm} (i.e., $\partial\Delta_1/\partial w_{gm} < 0$ and $\partial\Delta_2/\partial w_{gm} < 0$) indicating that the lower is w_{gm}, the more likely it is for countries to find it optimal to label their produce.

The reasoning is as follows. A reduction in w_{gm} (due to low market power of the life science sector and/or lax enforcement of its IPRs) increases the production share of the GM crop. The increased production share of the GM crop increases the utility discount factor associated with the consumption of the non-labeled product (see equation (24)), and reduces the consumer demand for the non-labeled product under the alternative Scenarios 3 and 4. Thus, the lower is the market power of the life science sector and/or the weaker is the enforcement of its IPRs, the less appealing is the no labeling regime, and the more likely it is that both countries will find it optimal to label their products.

Conversely, the greater is the market power of the life science sector and/or the stronger is the enforcement of IPRs, the less appealing is labeling, and the greater is the likelihood that countries will find it optimal to not label their products. Formally, the greater is w_{gm}, the greater are Δ_3 and Δ_4 (i.e., $\partial\Delta_3/\partial w_{gm} > 0$ and $\partial\Delta_4/\partial w_{gm} > 0$), and the greater is the likelihood that Scenario 2 will be a Nash equilibrium.

It follows that differences in the market power of the life science sector and/or differences in the strength of IPRs between the two countries can rationalize the establishment of different labeling regimes. In particular, a high degree of market power and/or strong IPRs in Country 1(2) combined with low market power and/or lax enforcement of IPRs in Country 2(1) can result in Scenario 3(4) being a Nash equilibrium in labeling strategies.

Cost effectiveness of the new technology

Similar to market power of the life science sector and the strength of IPRs, the cost effectiveness of the new technology affects the cost of producing the GM crop. The more cost effective is the new technology, the greater are Δ_1 and Δ_2, and the more likely it is that Scenario 1 will emerge as a Nash equilibrium in labeling strategies. The reasoning is as follows. The greater is the cost effectiveness of the GM technology, the greater is the production share of GM products, the lower is the consumer demand for non-labeled products, and the lower is the producer welfare under a no-labeling regime. Thus, the more effective is the new technology in reducing the costs of production, the more likely it is that countries that have adopted the GM technology will find it optimal to label their products.

It follows that a low cost effectiveness of the GM technology in both countries, enhances the desirability of the no labeling regime and makes the emergence of Scenario 2 as a Nash equilibrium more likely. On the other hand, an asymmetric effect of the GM technology on the cost of production might result in different labeling strategies in the two countries. In such a case, the country for which the new technology is highly cost effective will label its products while the country enjoying relatively small gains from the GM technology will opt for a no labeling regime. Thus, a high cost effectiveness of the GM technology in Country 1(2) combined with a low cost effectiveness in Country 2(1) can result in Scenario 4(3) being a Nash equilibrium.

Table 3 summarizes the conditions facilitating the different Nash equilibria in labeling strategies considered in this study. It is important to point out that the conditions presented in Table 3 represent depictions of the general environment in which different configurations of labeling strategies are likely to constitute a Nash equilibrium. Since it is the interaction of all these factors that determine whether a profile of labeling strategies will be a Nash equilibrium or not, the conditions presented in Table 3 should be viewed as sufficient, and not as necessary, conditions for the different labeling scenarios to constitute a Nash equilibrium.

It is possible, for instance, that a low cost effectiveness of the GM technology will be present in an environment in which both countries label their products. This could occur when the impact of a high consumer aversion and/or low segregation costs and/or low market power of the life science sector and/or lax IPR enforcement outweigh the impact of low cost effectiveness making labeling the optimal regulatory response in both regions.

Before concluding this section it is interesting to note that while our analysis assumes that the countries' objective is to maximize domestic producer welfare, the results summarized in Table 3 are more general and apply to cases where the producing countries seek to maximize their share of the world market, i.e., the conditions that maximize domestic producer welfare can be shown to maximize the market shares of the producing regions.

Finally, it should be mentioned that the determinants of the optimal labeling policy of the GM producing countries (and, therefore, the determinants of the Nash equilibrium in labeling strategies) identified in this study are the same no matter if domestic consumer welfare is a direct argument in countries' objective function or not. The reason is that the conditions that make labeling (no labeling) the optimal strategy for the GM producing regions are exactly those that result in labeling (no labeling) being the regime that maximizes *aggregate* consumer welfare. As shown by Giannakas and Fulton (2002), consumers as a group are better off under a labeling (no labeling) regime when their aversion to GM products is high (low), segregation costs are low (high), and the adoption of the GM technology is high (low). Recall that adoption of the GM technology is high (low) under high (low) cost effectiveness of this technology, low (high) market power of the innovating firms, and weak (strong) IPRs.

TABLE 3. Conditions facilitating the different Nash equilibria

		Country 2	
		Labeling	**No Labeling**
Country 1	**Labeling**	*Scenario 1* - High consumer aversion to GM products - Low segregation costs - Low degree of market power by the life science sector - Weak IPRs - High cost effectiveness of GM technology	*Scenario 4* - Low segregation costs in C.1 & High segregation costs in C.2 - Low degree of market power by the life science sector in C.1 & High market power in C.2 - Weak IPRs in C.1 & Strong IPRs in C.2 - High cost effectiveness of GM technology in C.1 & Low cost effectiveness in C.2
	No Labeling	*Scenario 3* - High segregation costs in C.1 & Low segregation costs in C.2 - High degree of market power by the life science sector in C.1 & Low market power in C.2 - Strong IPRs in C.1 & Weak IPRs in C.2 - Low cost effectiveness of GM technology in C.1 & High cost effectiveness in C.2	*Scenario 2* - Low consumer aversion to GM products - High segregation costs - High degree of market power by the life science sector - Strong IPRs - Low cost effectiveness of GM technology

7. Conclusions

This paper develops a stylized four-region model of heterogeneous producers and consumers to analyze the strategic interdependence between a small number of large producing countries that have adopted the GM technology and seek to determine their regulatory response to products of biotechnology (i.e., whether to label their GM and conventional produce or not). The framework of analysis developed in this study builds on the research by Giannakas and Fulton (2002) and Fulton and Giannakas (2004) that examines market and welfare effects of the GM technology, by placing the analysis of labeling decisions in a multi-country context. To our knowledge, the effect of strategic interdependence on countries' labeling decisions has not been considered previously.

The strategic interaction between the GM producing countries is modeled in this paper as a strategic game where the countries determine their labeling regimes non-cooperatively (i.e., independently but aware that their labeling strategies affect each other's payoffs). In this context, the paper examines the strategic effects of labeling decisions and identifies the determinants of the non-cooperative Nash equilibrium labeling regimes in these GM producing countries. In doing so, we are able to determine the environment in which each labeling configuration is likely to emerge as a Nash equilibrium i.e., the conditions under which the different configurations of labeling strategies can constitute a Nash equilibrium.

Analytical results show that the Nash equilibrium configuration of labeling regimes in countries that have adopted the GM technology depends on (i) the distribution of consumer preferences and the level of consumer aversion to GM products; (ii) the size of the segregation and labeling costs in these countries; (iii) the relative productive efficiency and the cost effectiveness of the GM technology; (iv) the market power of the life science companies; and (v) the strength of intellectual property rights in these countries.

Specifically, the greater (lower) is the consumer aversion to GM products and/or the smaller (greater) is the size of the segregation costs associated with a labeling regime in these countries and/or the greater (smaller) is the cost effectiveness of the new technology and/or the lower (greater) is the market power of the life science sector and/or the weaker (stronger) are the intellectual property rights in these countries, the more likely it is that GM producing countries will find it optimal to label (not label) their products.

While a similarity in these market and agronomic characteristics leads to uniform labeling standards in the GM producing regions, a divergence in the segregation costs, productive efficiency, cost effectiveness of the GM technology, market power and/or enforcement of IPRs between the different countries can lead to different regulatory responses to products of biotechnology. Different market and/or agronomic characteristics can, therefore, provide an explanation for the different approaches to labeling adopted in different countries around the world.

In addition to providing insights on the factors affecting countries' decisions on the regulation and labeling of products of biotechnology, the stylized framework of analysis developed in this paper can provide the basis for the economic analysis of important issues like the recent introduction of mandatory labeling by the EU and Brazil's formal entry into the market(s) for GM crops. Interesting extensions of this research could also include the explicit consideration of the optimal regulatory response by the rest of the world and the identification of the conditions that could lead in the worldwide adoption of biotechnology and/or the labeling of GM products.

Glossary

A: producers' differentiating attribute

A_{gmi}^{l} : total quantity of GM-labeled products supplied by Country i ($i \in \{1,2,\}$)

A_{gmi}^{nl} : total quantity of non-labeled GM products supplied by Country i

A_{gm}^{Sj} : quantity of GM-labeled products supplied under Scenario j ($j \in \{1,2,3,4\}$)

A_{nli}^{nl} : total quantity of non-labeled products supplied by Country i

A_{nl}^{Sj} : quantity of non-labeled products supplied under Scenario j

A_{ti}^{l} : total quantity of conventional-labeled products supplied by Country i

A_{ti}^{nl} : total quantity of non-labeled conventional products supplied by Country i

A_{t}^{Sj} : quantity of conventional-labeled products supplied under Scenario j

A_{Ti}^{l} : total quantity of labeled products supplied by Country i

c: consumers' differentiating attribute

D_{gm}^{j} : total demand for GM-labeled products under Scenario j

D_{nl}^{j} : total demand for non-labeled products under Scenario j

D_{t}^{j} : total demand for conventional-labeled products under Scenario j

$E\left(U_{nl}^{Sj}\right)$: expected utility associated with the consumption of non-labeled product under Scenario j

P_{gm}^{Dj} : per unit retail price of GM-labeled products under Scenario j

P_{gm}^{S} : per unit farm price of GM-labeled products

P_{gm}^{Sj} : per unit farm price of GM-labeled products under Scenario j

P_{gm}^{Sj*} : equilibrium farm price of GM-labeled products under Scenario j

P_{nl}^{Dj} : per unit retail price of non-labeled products under Scenario j

P_{nl}^{S} : per unit farm price of non-labeled products

P_{nl}^{Sj} : per unit farm price of non-labeled products under Scenario j

P_{nl}^{Sj*} : equilibrium farm price of non-labeled products under Scenario j

P_{s} : per unit retail price of the substitute product

P_{t}^{Dj} : per unit retail price of conventional-labeled products under Scenario j

P_{t}^{S} : per unit farm price of conventional-labeled products

P_t^{Sj} : per unit farm price of conventional-labeled products under Scenario j

P_t^{Sj*} : equilibrium farm price of conventional-labeled products under Scenario j

S_{gm}^{j} : total supply of GM-labeled products under Scenario j

S_{gmi}^{j} : supply of GM-labeled products by Country i under Scenario j

S_{nl3}^{j} : supply of non-labeled products by the R.O.W. under Scenario j

S_{nl}^{j} : total supply of non-labeled products under Scenario j

S_{nli}^{j} : supply of non-labeled products by Country i under Scenario j

S_{t3}^{j} : supply of conventional-labeled products by the R.O.W. under Scenario j

S_{t}^{j} : total supply of conventional-labeled products under Scenario j

S_{ti}^{j} : supply of conventional-labeled products by Country i under Scenario j

U : per unit base level of utility associated with the consumption of a product

U_{gm}^{Sj} : per unit utility associated with the consumption of GM-labeled product under Scenario j

U_{t}^{Sj} : per unit utility associated with the consumption of conventional-labeled product under Scenario j

U_s : per unit utility associated with the consumption of a substitute product

w_{gmi}^{l} : per unit base cost associated with the production of GM-labeled products in Country i

w_{gmi}^{lj} : per unit base cost associated with the production of GM-labeled products in Country i under Scenario j

w_{gmi}^{nl} : per unit base cost associated with the production of non-labeled GM product in Country i

w_{ti}^{l} : per unit base cost associated with the production of conventional-labeled products in Country i

w_{ti}^{nl} : per unit base cost associated with the production of non-labeled conventional products in Country i

x_{gm}^{ej} : equilibrium quantity of GM-labeled products traded under Scenario j

x_{gmi}^{ej} : equilibrium quantity of GM-labeled products by Country i traded under Scenario j

x_{gm}^{Sj} : quantity of GM-labeled products demanded under Scenario j

x_{nl3}^{ej} : equilibrium quantity of non-labeled products by the R.O.W. traded under Scenario j

x_{nl}^{ej} : equilibrium quantity of non-labeled products traded under Scenario j

x_{nli}^{ej} : equilibrium quantity of non-labeled products by Country i traded under Scenario j

x_{nl}^{Sj} : quantity of non-labeled products demanded under Scenario j

x_{t3}^{ej} : equilibrium quantity of conventional-labeled products by the R.O.W. traded under Scenario j

x_{t}^{ej} : equilibrium quantity of conventional-labeled products traded under Scenario j

x_{ti}^{ej} : equilibrium quantity of conventional-labeled products by Country i traded under Scenario j

x_{t}^{Sj} : quantity of conventional-labeled products demanded under Scenario j

x_{T}^{Sj} : total quantity of labeled products demanded under Scenario j

α_i : cost enhancement factor associated with the production of GM products in Country i

β_i : cost enhancement factor associated with the production of conventional products in Country i

λ : utility discount factor associated with the consumption of GM-labeled products

μ : utility discount factor associated with the consumption of conventional-labeled products

π_a : per unit net return function for the alternative product

π_{gm}^{l} : per unit net return function for GM-labeled products

π_{gm}^{nl} : per unit net return function for non-labeled GM products

π_{t}^{l} : per unit net return function for conventional-labeled products

π_{t}^{nl} : per unit net return function for non-labeled conventional products

Π_i^{l} : aggregate producer welfare in Country i under a labeling regime

Π_i^{lj} : equilibrium aggregate producer welfare in Country i under labeling in Scenario j

Π_i^{nl} : aggregate producer welfare in Country i under a no labeling regime

Π_i^{nlj} : equilibrium aggregate producer welfare in Country *i* under no labeling in Scenario *j*

ϕ : utility discount factor associated with the consumption of non-labeled products

χ_{gmi} : demand conjectural variation elasticity of the life science sector in Country *i*

ψ : global production share of the GM product in the total quantity of non-labeled products supplied

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