

## Regulation and Trade of GMOS

### **Veyssiere Luc**

Graduate Student  
Department of Economics  
Iowa State University  
260 Heady Hall  
Ames, IA 50011-1070  
Phone: (515) 296-4818  
Fax: (515) 294-0221  
luc@iastate.edu

### **Konstantinos Giannakas**

Associate Professor  
Department of Agricultural Economics  
University of Nebraska-Lincoln  
216 H.C. Filley Hall  
Lincoln, NE 68583-0922  
Phone: (402) 472-2041  
Fax: (402) 472-3460  
kgiannakas@unl.edu



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## REGULATION AND TRADE OF GMOS

**Abstract** - This 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 have adopted the GM technology. Analytical results show that the equilibrium labeling regimes depend on (i) the distribution of consumer preferences and the level of consumer aversion to GM products; (ii) the segregation and labeling costs in these countries; (iii) the relative productive efficiency and the cost effectiveness of the GM technology; (iv) the structure of the trading sector; (v) the market power of the life science companies; and (vi) the strength of intellectual property rights in these countries.

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; Hobbs and Plunkett, 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) oppose 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 issues related to the labeling of GM products see also Caswell (1998), Runge and Jackson (2000), Crespi and Marette (2003), and Fulton and Giannakas (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 an important factor, there are other parameters that are also significant in shaping the regulatory responses to the 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 explicitly consider 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 1 discusses the methodology and assumptions employed in our analysis. Sections 2 and 3 examine the producer and consumer decisions under alternative labeling regimes. Section 4 derives the equilibrium conditions in the world market under various labeling regimes and different scenarios on the market power of the trading sector. Section 5 derives the payoff matrix of the game and identifies the conditions that facilitate alternative Nash equilibria in labeling strategies. Section 6 summarizes and concludes the paper.

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

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. 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.

		Country 2	
		Labeling	No Labeling
Country 1	Labeling	<i>Scenario 1</i> GM-labeled product, Conventional (labeled and non-labeled) product	<i>Scenario 4</i> GM-labeled product, Conventional-labeled product, Non-labeled product
	No Labeling	<i>Scenario 3</i> GM-labeled product, Conventional-labeled product, Non-labeled product	<i>Scenario 2</i> Non-labeled product

Table 1: Products supplied under different labeling regimes

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 consumer 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.

*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.

As mentioned previously, the objective of each GM producing country is to determine the labeling regime that maximizes the welfare of its producers. 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 follows Giannakas and Fulton (2002) and Fulton and Giannakas (2004) and explicitly accounts for heterogeneous consumer preferences for GM and conventional products.

## 2. 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.

### *Production Decisions in Countries that Have Adopted the GM Technology* *Mandatory Labeling: Production Decisions in Country $i$*

As mentioned previously, producers in each producing region are assumed to differ in the returns they receive from the different crops. Let  $A \in [0, A]$  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 net returns to the production of the different crops are given by:

$$\begin{aligned} \pi_{gm}^l &= P_{gm}^S - (\alpha_i A + w_{gmi}^l) && \text{If a unit of the GM crop is produced} \\ \pi_i^l &= P_i^S - (\beta_i A + w_{ii}^l) && \text{If a unit of conventional crop is produced} \\ \pi_a &= 0 && \text{If a unit of alternative crop is produced} \end{aligned}$$

To save on notation, the net returns to the alternative crop are assumed to be constant among producers and equal to zero.  $P_{gm}^S$  and  $P_i^S$  stand for the unit farm prices for the GM and conventional crops, respectively, with  $P_{gm}^S < P_i^S$  (i.e., the conventional crop receives a premium).  $w_{gmi}^l$  and  $w_{ii}^l$  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 by producers of the conventional product (Fulton and Giannakas, 2004),  $w_{ii}^l$  is assumed to exceed  $w_{gmi}^l$ .

The parameters  $\alpha_i$  and  $\beta_i$  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  $\alpha_i A + w_{gmi}^l$  and  $\beta_i A + w_{ii}^l$ , 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. To capture the observed coexistence of GM and conventional crops, the agronomic parameter  $\alpha_i$  is assumed greater

than  $\beta_i$  (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. A farmer's production decision is determined by the relative returns associated with the different crops. Figure 1 graphs  $\pi_{gm}^l$  and  $\pi_t^l$  and illustrates the producer decisions when price and cost parameters are such that the GM technology is non-drastring and both crops enjoy positive production shares.

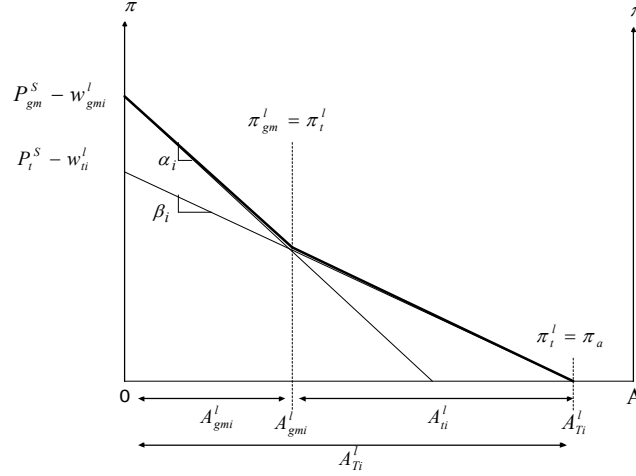


Figure 1: Production decisions and welfare under mandatory labeling

The farmer with differentiating attribute  $A_{gmi}^l$  (determined by the intersection of  $\pi_{gm}^l$  and  $\pi_t^l$ ) 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  $A_{gmi}^l$  (i.e. producers with  $A \in [0, A_{gmi}^l)$ ) find it profitable to produce the GM crop. Since producers have been assumed to be uniformly distributed within 0 and A,  $A_{gmi}^l$  gives the quantity of the GM crop produced in Country  $i$ .

$$\text{Mathematically } A_{gmi}^l = \frac{P_{gm}^S - w_{gmi}^l - P_t^S + w_{ti}^l}{(\alpha_i - \beta_i)} \quad (1)$$

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

$$A_{T_i}^l = \frac{P_t^S - w_{ti}^l}{\beta_i} \quad (2)$$

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

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

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

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

### 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:

$$\begin{aligned}\pi_{gm}^{nl} &= P_{nl}^S - (\alpha_i A + w_{gmi}^{nl}) && \text{If a unit of GM crop is produced} \\ \pi_t^{nl} &= P_{nl}^S - (\beta_i A + w_{ti}^{nl}) && \text{If a unit of conventional crop is produced} \\ \pi_a &= 0 && \text{If a unit of alternative crop is produced}\end{aligned}$$

where  $P_{nl}^S$  is the farm price when the GM and conventional crops are marketed together.  $w_{gmi}^{nl}$  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 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), 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)-(3) i.e.,

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

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

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

Aggregate producer welfare in Country  $i$  under a no labeling regime is given by:

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

### 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. Following the same reasoning the quantity of non-labeled conventional crop supplied by the R.O.W. is given by:

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

### 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 give 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. The mathematical expressions for the total supplies under all four scenarios are presented in Table 2.

Note that in the absence of labeling in Scenario 2, only one supply channel emerges that corresponds to the summation of the supply by all three countries. In Scenarios 3 and 4, 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).

Scenarios	Crop	World supply
1	GM	$P_{gm}^{S1} = aA_t^{S1} + (g+a)A_{gm}^{S1} + (b-h)w_{i1}^l + (c-i)w_{i2}^l + dw_{i3} + hw_{gm1}^l + iw_{gm2}^l$ (10)
	Conv.	$P_t^{S1} = aA_t^{S1} + aA_{gm}^{S1} + bw_{i1}^l + cw_{i2}^l + dw_{i3}$ (11)
2	Non Lab.	$P_{nl}^{S2} = aA_{nl}^{S2} + bw_{i1}^{nl} + cw_{i2}^{nl} + dw_{i3}$ (12)
3	GM	$P_{gm}^{S3} = \alpha_2 A_{gm}^{S3} + \beta_2 A_t^{S3} + w_{gm2}^{l3}$ (13)
	Non Lab.	$P_{nl}^{S3} = mA_{nl}^{S3} + nw_{i1}^{nl} + ow_{i3}$ (14)
	Conv.	$P_t^{S3} = \beta_2 A_t^{S3} + \beta_2 A_{gm}^{S3} + w_{i2}^l$ (15)
4	GM	$P_{gm}^{S4} = \alpha_1 A_{gm}^{S4} + \beta_1 A_t^{S4} + w_{gm1}^{l4}$ (16)
	Non Lab.	$P_{nl}^{S4} = pA_{nl}^{S4} + qw_{i2}^{nl} + rw_{i3}$ (17)
	Conv.	$P_t^{S4} = \beta_1 A_t^{S4} + \beta_1 A_{gm}^{S4} + w_{i1}^l$ (18)

Table 2: World Supplies Equations under all four scenarios

$$\text{with } a = \frac{\beta_1 \beta_2 \beta_3}{\beta_1 \beta_2 + \beta_2 \beta_3 + \beta_1 \beta_3}, b = \frac{a}{\beta_1}, c = \frac{a}{\beta_2}, d = \frac{a}{\beta_3}, g = \frac{(\alpha_1 - \beta_1)(\alpha_2 - \beta_2)}{(\alpha_1 - \beta_1) + (\alpha_2 - \beta_2)}, h = \frac{g}{(\alpha_1 - \beta_1)}$$

$$i = \frac{g}{(\alpha_2 - \beta_2)}, m = \frac{\beta_1 \beta_3}{\beta_1 + \beta_3}, n = \frac{\beta_3}{\beta_1}, o = \frac{m}{\beta_3}, p = \frac{\beta_2 \beta_3}{\beta_2 + \beta_3}, q = \frac{p}{\beta_2} \text{ and } r = \frac{q}{\beta_3}$$

### 3. Consumption Decisions and Determination of Total Demands

This section focuses on consumer purchasing decisions under each of the scenarios presented in Table 1. To retain tractability and focus on the effect of strategic interdependence on GM producing countries' labeling decisions, a unique consuming region encompassing the world consumers is considered. The framework of analysis used (Giannakas and Fulton, 2002 and Fulton and Giannakas, 2004) allows for heterogeneous consumer preferences for GM and conventional products.

#### *Consumption Decisions under Scenario 1 (Both countries label their products)*

Let  $c \in [0, C]$  be the attribute that differentiates consumers. Its value 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:

$$U_{gm}^1 = U - P_{gm}^{D1} - \lambda c \quad \text{If a unit of GM product is consumed}$$

$$U_t^1 = U - P_t^{D1} - \mu c \quad \text{If a unit of conventional product is consumed}$$

$$U_s = U - P_s \quad \text{If a unit of a substitute product is consumed}$$

$U$  is a per unit base level of utility associated with the consumption of a product and it is common to all consumers.  $P_{gm}^{D1}$ ,  $P_t^{D1}$  and  $P_s$  denote the retail prices of the GM, the conventional and the substitute product, respectively.  $\lambda$  and  $\mu$  are positive utility discount factors associated with the consumption of the GM and conventional products, respectively, so that the terms  $\lambda c$  and  $\mu c$  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  $\lambda - \mu$  capturing the level of consumer aversion to GM products. To save on notation, we assume that all consumers place the same value on the substitute product.

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 2 graphs  $U_{gm}^1$ ,  $U_t^1$  and  $U_s$  and illustrates the consumer purchasing decisions for the case in which the prices and preference parameters are such that all products enjoy positive market shares. The consumer with differentiating attribute  $c_{gm}^1$  (determined by the intersection of  $U_{gm}^1$  and  $U_t^1$ ) is indifferent between purchasing the conventional product and its GM counterpart – the utility associated with the consumption of these products is the same.

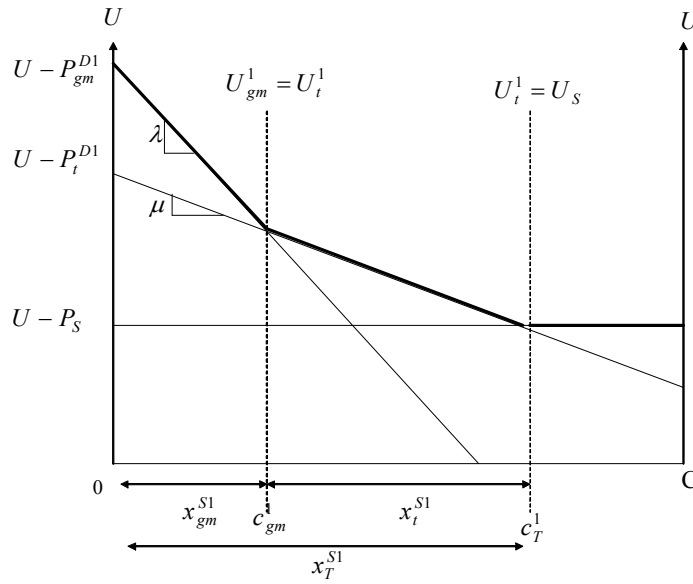


Figure 2: Consumption decisions under Scenario 1

Consumers located to the left of  $c_{gm}^1$  prefer the GM product while consumers located to the right of  $c_{gm}^1$  opt buying either the conventional product or the substitute product. When consumers are uniformly distributed between 0 and C,  $c_{gm}^1$  gives the quantity of the GM product consumed in the

world market under Scenario 1,  $x_{gm}^{S1}$ . Mathematically it corresponds to:  $x_{gm}^{S1} = \frac{P_t^{D1} - P_{gm}^{D1}}{\lambda - \mu}$  (19)

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

$$x_T^{S1} = \frac{P_s - P_t^{D1}}{\mu} \quad (20)$$

while, subtracting  $x_{gm}^{S1}$  from  $x_T^{S1}$  gives the total demand for the conventional product as:

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

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

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

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



*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 a choice between the non-labeled product and its substitute and the utility function is:

$$\begin{aligned} E(U_{nl}^2) &= U - P_{nl}^{D2} - \phi c && \text{If a unit of non-labeled product is consumed} \\ U_s &= U - P_s && \text{If a unit of the substitute product is consumed} \end{aligned}$$

where  $P_{nl}^{D2}$  is the retail price of the non-labeled product, and  $\phi$  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,  $\psi$ , the greater is the perceived probability that the non-labeled product is GM, and the lower is the utility associated with its consumption. The utility discount factor associated with the consumption of the non-labeled product,  $\phi$ , is given by:

$$\phi = \psi\lambda + (1 - \psi)\mu = \psi(\lambda - \mu) + \mu \quad (24)$$

where  $\psi = \frac{A_{gm/nl}^{S2}}{A_{nl}^{S2}}$  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  $\psi$  can be rewritten as:

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

The consumer demand for the non-labeled product,  $x_{nl}^{S2}$ , when  $P_s > P_{nl}^{D2}$  is given by:

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

and its inverse form can be written as:

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

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)).

*Consumption Decisions under Scenarios 3 and 4 (One country labels its products)*

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

$$\begin{aligned} U_{gm} &= U - P_{gm}^D - \lambda c && \text{If a unit of GM product is consumed} \\ E(U_{nl}) &= U - P_{nl}^D - \phi' c && \text{If a unit of non-labeled product is consumed} \\ U_t &= U - P_t^D - \mu c && \text{If a unit of conventional product is consumed} \\ U_s &= U - P_s && \text{If a unit of the substitute product is consumed} \end{aligned}$$

with  $\phi' \neq \phi$  because  $\psi' \neq \psi$ . 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),  $\psi_3$  is given by:

$$\psi_3 = \frac{e(w_{t1}^{nl} - w_{gm1}^{nl})}{A_{nl}^{S3}} \quad (28) \quad \text{and becomes } \psi_4 = \frac{f(w_{t2}^{nl} - w_{gm2}^{nl})}{A_{nl}^{S4}} \quad (29)$$

when only Country 1 labels its products (Scenario 4).

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

$$x_{gm} = \frac{P_{nl}^D - P_{gm}^D}{(1-\psi)(\lambda - \mu)} \quad (30)$$

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

$$x_t = \frac{P_s - P_t^D}{\mu} - \frac{P_t^D - P_{nl}^D}{\psi(\lambda - \mu)} \quad (32)$$

The inverse form of these demands is then:

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

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

$$P_t^D = P_s - \mu x_t - \mu x_{nl} - \mu x_{gm} \quad (35)$$

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

#### 4. 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 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.

##### *Market Outcomes under Scenario 1*

Consider first the case when the trading sector is perfectly competitive and trading costs are normalized to zero. In this case, two distinct supply channels provide GM and conventional products to consumers in the world market and the consumer prices are equal to those received by farmers, i.e.,

$$P_{gm}^{D1} = P_{gm}^{S1} \quad (36)$$

$$P_t^{D1} = P_t^{S1} \quad (37)$$

The market clearing condition implies that:

$$A_{gm}^{S1} = x_{gm}^{S1} = x_{gm}^{e1} \quad (38)$$

$$A_t^{S1} = x_t^{S1} = x_t^{e1} \quad (39)$$

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

When the trading sector is able to exercise market power both when buying and when selling conventional and GM products, the equilibrium quantities traded in the world market are determined by the equality of the “marginal revenues”, "MR", and “marginal expenditures”, "ME", as perceived by the trading firms in each market, i.e.,

$$x_{gm}^{e1} : "MR_{gm}" = "ME_{gm}" \Rightarrow P_{gm}^{D1} - \lambda \theta_{gm} x_{gm}^{e1} = P_{gm}^{S1} + (g + a) \varepsilon_{gm} x_{gm}^{e1} \quad (40)$$

$$x_t^{e1} : "MR_t" = "ME_t" \Rightarrow P_t^{D1} - \mu \theta_t x_t^{e1} = P_t^{S1} + a \varepsilon_t x_t^{e1} \quad (41)$$

where  $\theta_{gm}$  and  $\theta_t$  denote the demand conjectural variation elasticities of the trading sector on the markets for GM and conventional products, respectively, and reflect the market power of the trading sector when selling these products downstream. Similarly, the parameters  $\varepsilon_{gm}$  and  $\varepsilon_t$  are the supply conjectural variation elasticities of the trading sector capturing the market power exercised by trading firms when procuring the GM and conventional crops from producers.

Substituting the expressions for the derived demands (equations (22) and (23)) and supplies (equations (10) and (11)) for the relevant parameters in equations (40) and (41), and solving the system of equations we get the equilibrium quantities in the two markets as:

$$x_{gm}^{e1} = \frac{(\mu\theta_t + a\varepsilon_t)}{D} P_s + \frac{h(a + \mu) + (h - b)(\mu\theta_t + a\varepsilon_t)}{D} w_{t1}^l + \frac{i(a + \mu) + (i - c)(\mu\theta_t + a\varepsilon_t)}{D} w_{t2}^l - \frac{d(\mu\theta_t + a\varepsilon_t)}{D} w_{t3}^l - \frac{h(\mu\theta_t + a\varepsilon_t + (a + \mu))}{D} w_{gm1}^{l1} - \frac{i(\mu\theta_t + a\varepsilon_t + (a + \mu))}{D} w_{gm2}^{l1} \quad (42)$$

$$x_t^{e1} = \frac{(g + a)\varepsilon_{gm} + \lambda\theta_{gm} + g + (\lambda - \mu)}{D} P_s - \frac{b((g + a)\varepsilon_{gm} + \lambda\theta_{gm} + g + (\lambda - \mu)) + h(a + \mu)}{D} w_{t1}^l - \frac{c((g + a)\varepsilon_{gm} + \lambda\theta_{gm} + g + (\lambda - \mu)) + i(a + \mu)}{D} w_{t2}^l - \frac{d((g + a)\varepsilon_{gm} + \lambda\theta_{gm} + g + (\lambda - \mu))}{D} w_{t3}^l + \frac{h(a + \mu)}{D} w_{gm1}^{l1} + \frac{i(a + \mu)}{D} w_{gm2}^{l1} \quad (43)$$

with  $D = ((g + a)(\varepsilon_{gm} + 1) + \lambda(1 + \theta_{gm}))(\mu(\theta_t + 1) + a(\varepsilon_t + 1)) - (a + \mu)^2$

Substituting equations (42) and (43) into the expressions for farm prices in equation (10) and (11), we get the equilibrium farm prices in the presence of market power by the trading sector as:

$$P_{gm}^{S1*} = ax_t^{e1} + (g + a)x_{gm}^{e1} + (b - h)w_{t1}^l + (c - i)w_{t2}^l + dw_{t3}^l + hw_{gm1}^{l1} + iw_{gm2}^{l1} \quad (44)$$

$$P_t^{S1*} = ax_t^{e1} + ax_{gm}^{e1} + bw_{t1}^l + cw_{t2}^l + dw_{t3}^l \quad (45)$$

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

$$\Pi_i^{l1*} = (P_{gm}^{S1*} - w_{gm1}^{l1}) \frac{(P_{gm}^{S1*} - w_{gm1}^{l1}) - (P_t^{S1*} - w_{ti}^l)}{2(\alpha_i - \beta_i)} + \frac{(P_t^{S1*} - w_{ti}^l)^2}{2\beta_i} \quad (46)$$

### Market Outcomes 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:

$$A_{nl}^{S2} = x_{nl}^{S2} = x_{nl}^{e2} \quad (47)$$

where  $x_{nl}^{e2}$  is the equilibrium quantity of non-labeled product traded in the world market.

When the trading sector can exercise market power both when selling and buying the non-labeled product, the equilibrium  $x_{nl}^{e2}$  is determined by:

$$x_{nl}^{e2} : "MR_{nl}" = "ME_{nl}" \Rightarrow P_{nl}^{D2} - \psi_2(\lambda - \mu)(\theta_{nl} - \varepsilon_{nl})x_{nl}^{e2} - \mu\theta_{nl}x_{nl}^{e2} = P_{nl}^{S2} + a\varepsilon_{nl}x_{nl}^{e2} \quad (48)$$

where  $\theta_{nl}$  and  $\varepsilon_{nl}$  are the conjectural variation elasticities of the trading sector on the demand and supply sides of the market, respectively. Following the same procedure outlined in the previous section, the equilibrium quantity is given by:

$$x_{nl}^{e2} = \frac{1}{\mu(\theta_{nl} + 1) + a(\varepsilon_{nl} + 1)} P_s - \frac{e(\lambda - \mu)(\theta_{nl} - \varepsilon_{nl} + 1) + b}{\mu(\theta_{nl} + 1) + a(\varepsilon_{nl} + 1)} w_{t1}^{nl} + \frac{e(\lambda - \mu)(\theta_{nl} - \varepsilon_{nl} + 1)}{\mu(\theta_{nl} + 1) + a(\varepsilon_{nl} + 1)} w_{gm1}^{nl} - \frac{f(\lambda - \mu)(\theta_{nl} - \varepsilon_{nl} + 1) + c}{\mu(\theta_{nl} + 1) + a(\varepsilon_{nl} + 1)} w_{t2}^{nl} + \frac{f(\lambda - \mu)(\theta_{nl} - \varepsilon_{nl} + 1)}{\mu(\theta_{nl} + 1) + a(\varepsilon_{nl} + 1)} w_{gm2}^{nl} - \frac{d}{\mu(\theta_{nl} + 1) + a(\varepsilon_{nl} + 1)} w_{t3}^l \quad (49)$$

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

$$P_{nl}^{S2*} = ax_{nl}^{e2} + bw_{t1}^{nl} + cw_{t2}^{nl} + dw_{t3}^l \quad (50)$$

$$\Pi_i^{nl2*} = (P_{nl}^{S2*} - w_{gm1}^{nl}) \frac{(w_{ti}^{nl} - w_{gm1}^{nl})^2}{2(\alpha_i - \beta_i)} + \frac{(P_{nl}^{S2*} - w_{ti}^{nl})^2}{2\beta_i} \quad (51)$$

### Market Outcomes under Scenarios 3 and 4

These scenarios involve 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:

$$x_{gm}^{S4} = A_{gm}^{S4} = x_{gm}^{e4} \quad (52)$$

$$x_{nl}^{S4} = A_{nl}^{S4} = x_{nl}^{e4} \quad (53)$$

$$x_t^{S4} = A_t^{S4} = x_t^{e4} \quad (54)$$

The equilibrium quantities of GM, conventional and non-labeled products traded in the world market ( $x_{gm}^{e4}$ ,  $x_t^{e4}$  and  $x_{nl}^{e4}$ ) in the presence of market power by the trading sector are given by:

$$x_{gm}^{e4} : "MR_{gm}" = "ME_{gm}" \Rightarrow P_{gm}^{D4} - \lambda \theta_{gm} x_{gm}^{e4} = P_{gm}^{S4} + \alpha_1 \varepsilon_{gm} x_{gm}^{e4} \quad (55)$$

$$x_{nl}^{e4} : "MR_{nl}" = "ME_{nl}" \Rightarrow P_{nl}^{D4} - \mu \theta_{nl} x_{nl}^{e4} - \psi_4 (\lambda - \mu) (\theta_{nl} - \varepsilon_{nl}) x_{nl}^{e4} + \psi_4 (\lambda - \mu) x_{gm}^{e4} \varepsilon_{nl} = P_{nl}^{S4} + p \varepsilon_{nl} x_{nl}^{e4} \quad (56)$$

$$x_t^{e4} : "MR_t" = "ME_t" \Rightarrow P_t^{D4} - \mu \theta_t x_t^{e4} = P_t^{S4} + \beta_1 \varepsilon_t x_t^{e4} \quad (57)$$

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

$$x_{gm}^{e4} = \frac{f(\mu \theta_t + \beta_1 \varepsilon_t + \mu + \beta_1)(\lambda - \mu)}{D_4} w_{gm2}^{nl} - \frac{(\mu \theta_t + \beta_1 \varepsilon_t + \mu + \beta_1)f(\lambda - \mu)}{D_4} w_{t2}^{nl} - \frac{(\mu \theta_t + \beta_1 \varepsilon_t + \mu + \beta_1)}{D_4} w_{gm1}^{l4} + \frac{(\mu + \beta_1)}{D_4} w_{t1}^l - \frac{\mu(\mu \theta_t + \beta_1 \varepsilon_t)}{D_4} x_{nl}^{e4} \quad (58)$$

$$x_{nl}^{e4} = \frac{Y_1 + \sqrt{(Y_1)^2 - 4X_1Z_1}}{2X_1} \quad (59)$$

$$x_t^{e4} = \frac{(\lambda \theta_{gm} + \alpha_1 \varepsilon_{gm} + (\lambda - \mu) + (\alpha_1 - \beta_1))}{D_4} P_s - \frac{(\lambda \theta_{gm} + \alpha_1 \varepsilon_{gm} + \lambda + \alpha_1)}{D_4} w_{t1}^l + \frac{(\mu + \beta_1)}{D_4} w_{gm1}^{l4} + \frac{f(\mu + \beta_1)(\lambda - \mu)}{D_4} w_{t2}^{nl} - \frac{f(\mu + \beta_1)(\lambda - \mu)}{D_4} w_{gm2}^{nl4} - \frac{\mu(\lambda \theta_{gm} + \alpha_1 \varepsilon_{gm} + (\lambda - \mu) + (\alpha_1 - \beta_1))}{D_4} x_{nl}^{e4} \quad (60)$$

The farm prices of the three products are then:

$$P_{gm}^{S4*} = \alpha_1 x_{gm}^{e4} + \beta_1 x_t^{e4} + w_{gm1}^{l4} \quad (61)$$

$$P_{nl}^{S4*} = p x_{nl}^{e4} + q w_{t2}^{nl} + r w_{t3} \quad (62)$$

$$P_t^{S4*} = \beta_1 x_t^{e4} + \beta_1 x_{gm}^{e4} + w_{t1}^l \quad (63)$$

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

$$\Pi_i^{l4*} = (P_{gm}^{S4*} - w_{gm1}^{l4}) \frac{(P_{gm}^{S4*} - w_{gm1}^{l4}) - (P_t^{S4*} - w_{t1}^l)}{2(\alpha_1 - \beta_1)} + \frac{(P_t^{S4*} - w_{t1}^l)^2}{2\beta_1} \quad (64)$$

$$\Pi_2^{nl4*} = (P_{nl}^{S4*} - w_{gm2}^{nl}) \frac{(w_{t2}^{nl} - w_{gm2}^{nl})}{2(\alpha_2 - \beta_2)} + \frac{(P_{nl}^{S4*} - w_{t2}^{nl})^2}{2\beta_2} \quad (65)$$

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

$$\Pi_1^{nl3*} = (P_{nl}^{S3*} - w_{gm1}^{nl}) \frac{(w_{t1}^{nl} - w_{gm1}^{nl})}{2(\alpha_1 - \beta_1)} + \frac{(P_{nl}^{S3*} - w_{t1}^{nl})^2}{2\beta_1} \quad (66)$$

$$\Pi_2^{l3*} = (P_{gm}^{S3*} - w_{gm1}^{l3}) \frac{(P_{gm}^{S3*} - w_{gm2}^{l3}) - (P_t^{S3*} - w_{t2}^l)}{2(\alpha_2 - \beta_2)} + \frac{(P_t^{S3*} - w_{t2}^l)^2}{2\beta_2} \quad (67)$$

## 5. 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, the payoff matrix for Countries 1 and 2 is formulated in Table 3.

### 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, the following inequalities have to hold:

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

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

*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, the following inequalities have to hold:

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

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

*Conditions for Scenario 3 and 4 being a Nash equilibrium*

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

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

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

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

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

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

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

Table 3: Payoff matrix

### *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 structure of the trading sector; (v) the market power of the life science companies; and (vi) 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. 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.

#### *Consumer aversion to GM products*

Consistent with *a priori* expectations, expressions  $\Delta_1$  and  $\Delta_2$  in equations (68) and (69) rise with an increase in the level of consumer aversion to GM products, 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  $\Delta_3$  and  $\Delta_4$ , 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  $\Delta_1$  and  $\Delta_2$  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  $\Delta_3$  and  $\Delta_4$  in (70) and (71), and the more likely it is for Scenario 2 to emerge as a 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  $\Delta_1$  and  $\Delta_2$  increase with a reduction in  $w_{gm}$  – 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  $\Delta_3$  and  $\Delta_4$ ,

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.

#### *Market power of the trading sector*

Obviously, an increase in the market power of the trading sector when selling the product downstream and/or when procuring the product from the producers, causes producer welfare to fall under all labeling scenarios. While market power of the trading sector reduces producer welfare both under labeling and no labeling regimes, it reduces producer welfare under no labeling by relatively more. The reasoning is as follows.

The reduction in farm prices due to increased market power of the trading sector when countries do not label their products reduces the producer returns to both the GM and conventional products. While the quantity of the non-labeled good produced (and traded) by each country falls, the production share of the GM crop in the total production of the non-labeled product increases.

The increased production share of the GM product due to increased market power by the trading sector increases the likelihood that the non-labeled product is GM and reduces the consumer demand for this product. Reduced consumer demand translates into reduced derived demand faced by the trading sector and a further reduction in the price received by producers under a no labeling regime. It is this demand effect (which is absent when the two GM producing regions label their products) that causes the market power of the trading sector to have a greater effect on producer welfare in countries that do not label their produce. In this context, the greater is the market power of the trading sector, the more likely it is that GM producing countries will label their products.

#### *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  $\Delta_1$  and  $\Delta_2$ , 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 4 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 4 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 4 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.

<b>Scenario 1</b>	<b>Scenario 4</b>
<ul style="list-style-type: none"> <li>- High consumer aversion to GM products</li> <li>- Low segregation costs</li> <li>- Low degree of market power by the life science sector</li> <li>- Weak IPRs</li> <li>- High degree of market power by the trading sector</li> <li>- High cost effectiveness of GM technology</li> </ul>	<ul style="list-style-type: none"> <li>- Low segregation costs in C.1 &amp; High segregation costs in C.2</li> <li>- Low degree of market power by the life science sector in C.1 &amp; High market power in Country 2</li> <li>- Weak IPRs in C.1 &amp; Strong IPRs in C.2</li> <li>- High cost effectiveness of GM technology in C.1 &amp; Low cost effectiveness in C.2</li> </ul>
<b>Scenario 3</b>	<b>Scenario 2</b>
<ul style="list-style-type: none"> <li>- High segregation costs in C.1 &amp; Low segregation costs in C.2</li> <li>- High degree of market power by the life science sector in C.1 &amp; Low market power in Country 2</li> <li>- Strong IPRs in C.1 &amp; Weak IPRs in C.2</li> <li>- Low cost effectiveness of GM technology in C.1 &amp; High cost effectiveness in C.2</li> </ul>	<ul style="list-style-type: none"> <li>- Low consumer aversion to GM products</li> <li>- High segregation costs</li> <li>- High degree of market power by the life science sector</li> <li>- Strong IPRs</li> <li>- Low degree of market power by the trading sector</li> <li>- Low cost effectiveness of GM technology</li> </ul>

Table 4: Conditions facilitating the different Nash equilibria

Before concluding the paper 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 conditions that make labeling (no labeling) the optimal strategy for both 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, weak (strong) IPRs, and high (low) market power of the trading sector.

## 6. 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 work by Giannakas and Fulton (2002) and Fulton and Giannakas (2004) that examine 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. 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 structure of the trading sector; (v) the market power of the life science companies; and (vi) 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, and/or the greater (lower) is the market power of the trading sector, 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.

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