

Identity Preservation and False Non-GMO Labeling in the Food Supply Chain

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Abstract

This paper addresses two issues pertaining to the market differentiation between non-genetically modified and genetically modified food varieties. First, a cost-efficiency explanation of the discrepancy between the observed shares of identity preserved non-genetically modified variety and the total supply of the variety is provided. Second, it is shown that when products can be falsely labeled as non-genetically modified, the share of false labeling depends on the level of identity preservation. Also in this context, it is demonstrated that the share of falsely labeled supply can increase in response to harsher fines.

Keywords: acreage allocation, identity preservation, food labeling, market differentiation, credence attributes

JEL Classification: Q110, D41

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Introduction

In the face of persistent consumer resistance, the wide adoption of biotechnology appears to stimulate the bulk commodity system of agricultural grain trading to split between traditional and genetically modified (GM) product varieties. Crop segregation and identity preservation (IP) practices are used to accommodate the emerging market differentiation between the products according to the GM content (e.g., Lin, Chambers, and Harwood). An interesting feature of this process is an apparent discord between the share of acres sown to non-GM crops and the share of non-GM crops that are processed through IP. While the upper limits for the potential market shares of non-GM corn and soybeans in the United States in 1999 were estimated at 37% and 31.6%, respectively, the actual demand was much smaller (Babcock and Beghin). For example, only a fraction of an estimated 4% of total corn production in 1998-2000 that was identity preserved was certified as non-GM (Palmer). According to a survey by the U.S. Grains Council, this figure was less than 3% in 2000 with a slight discrepancy between the responses from farmers and elevators (*Agriculture and Biotechnology Strategies*).¹ In contrast, depending on the crop, between 50% and 70% of the U.S. acreage was sown to non-GM varieties of corn and soybeans in 1998-2001.

This implies that the supply of non-GM varieties could fetch only a minor premium at harvest because it apparently exceeded the derived demand for non-GM varieties.² This was, in fact, the case, as an estimated historical price premium for non-GM varieties amounted to less than 2%-4% of the average price received by U.S. farmers³ (European Commission, U.S. FDA). If, indeed, GM varieties are credited with offering a cheaper production technology,

¹ However, according to one industry survey in 1999, 11% of Midwest elevators segregated for non-GM corn and 8% segregated for non-GM soybeans. Still, only 1% and 3% of those elevators offered premiums for, respectively, non-GM corn and soybeans (USDA).

² When identifying crops as non-GM, the tolerance level for the presence of GM material is of crucial importance. Even though a significant share of harvested acres sown to non-GM varieties is likely to fail to produce a “pure” non-GM crop, the gap between the shares of IP and the supply of non-GM varieties is striking. Also, the issue of contamination due to cross-pollination is of much less importance for some crops than for others (e.g., soybeans.)

³ Premiums for non-GM corn and soybeans offered by elevators and grain terminals varied widely depending on location and proximity to export ports. However, only a small share of elevators engaged in crop segregation (USDA).

then low average premiums received for non-GM varieties, at least ex post, do not appear to be sufficient to warrant the costlier production.⁴ In this paper, I propose a production cost efficiency argument that may contribute to explaining the observed breach between the production decisions at the growing and processing stages of the U.S. food supply chain. I also consider how the possibility of false labeling alters the incentives of the players in agricultural markets.

The rest of the paper is organized as follows. The numbered sections to follow explain the elements of the model of market differentiation and the essence of the cost efficiency argument. Then the formal model is developed. After describing the production and consumption environments, I define and characterize the IP cost efficient equilibrium. Next, I explore some properties of a constrained IP cost efficient equilibrium and discuss principal assumptions underpinning the analysis. Then I extend the set of food marketing strategies to include false labeling and investigate some of the properties of the equilibrium share of false labels.

Elements of the Model

[You might add some text here to better introduce this breakdown of the model elements and essence of your argument. This section is a little awkward here standing on its own.]

1. Food Chain and Market Differentiation

On the demand side, consumers' value of input-trait GM varieties is, on average, lower than that of non-GM counterparts. On the supply side, growing and segregating non-GM varieties typically involves greater production expenses than does growing GM varieties. The arising trade-off between output prices and production costs has been proposed as the main motive behind the incomplete adoption of GM varieties (Saak and Hennessy). Building on their approach, I will detail the origin of the demand that growers face at harvest. In a perfectly competitive environment, I consider a two-stage production process. In the first stage, a

⁴ Overall, the evidence that GM varieties provide significant cost savings appears moot (European Commission). Nevertheless, the motive for the rapid adoption of herbicide-tolerant and pest-resistant GM varieties is not likely to lie on the demand side.

fixed stock of land is allocated between GM and non-GM varieties. The decision to invest in the IP processing is made in the second stage, when the crops are sold to processors.

2. Identity Preservation and Production Externalities

The unit cost of IP is likely to be subject to two types of production externalities. When the share of non-GM variety at harvest increases, the average IP cost may fall due to a lower probability of commingling as well as search and transportation costs. Note that, in the extreme case, when no GM variety is supplied at harvest, the cost of IP is zero. For precisely the same reasons, IP processing may tend to be more expensive when the share of IP increases. The marginal cost of IP escalates to infinity when IP processors demand all non-GM variety. In contrast, as specialized marketing channels emerge, it seems probable that economies –of scale work to reduce the unit cost of IP (e.g., Lin, Chambers, and Harwood). In what follows, both possibilities will be considered. But for now consider that the average cost of IP is lower when only part of non-GM variety is IP processed than when the entire supply of the variety is IP processed.⁵

3. Efficient Allocation and Competitive Markets

Therefore, competitive markets face the following efficient allocation problem. On the one hand, non-GM growers impose a positive externality on IP processors when supply of non-GM variety exceeds demand. In contrast, a premium for non-GM variety emerges only if all of the variety is demanded for IP processing. Therefore, non-GM growers never choose to produce any “excess” amount of non-GM variety. However, as will be shown, competitive markets can achieve the efficient allocation through randomization that, at least partially, internalizes the production externalities described above. Namely, competitive markets can oscillate between two equilibria: one where only a part of non-GM variety is IP, and the other where all of the variety is IP processed. Then, on average, non-GM growers receive a premium and therefore a “sufficient” supply of non-GM variety is secured. And so, IP

⁵ Lin, Chambers, and Harwood conjecture that “rough ballpark figures” reflecting additional processing costs due to segregation could be as high as \$0.22/bushel for non-biotech corn and \$0.54/bushel for non-biotech soybeans (marketed from country elevator to export elevator) net of the grower’s premium. Bullock, Desquilbet, and Nitsi (2000) present an alternative, more conservative set of such estimates.

processing costs are reduced when the share of IP is small relative to supply. Next, I describe the demand environment that is likely to support such randomization.

4. Premium for IP Food Products

Observe that when only part of non-GM variety is processed through IP, a given non-IP product may turn out to contain very little GM material. Therefore, consumers must value non-IP products more than pure GM food products. As the share of IP processed non-GM variety increases, two things happen. On one hand, the price of IP products declines because the aggregate demand schedule is downward sloping. On the other hand, there are fewer chances that a non-IP food product is free of genetically modified organisms (GMO), which implies that its value to consumer falls as well. Hence, in general, the price premium for IP non-GM variety can actually rise when the level of IP increases. Under certain conditions in the distribution of tastes toward GM food among the population and assuming the average cost of IP, this will be shown to generate multiple equilibria in the processing stage. Then the event that non-GM growers receive a premium becomes uncertain, given that other equilibrium outcomes are possible.

5. Labeling of IP Products

Since the GM content of a final food product typically is a credence attribute, differentiation between IP and non-IP products at the retail level is performed through non-GMO labeling (e.g., Caswell and Mojduszka 1996).⁶ On the legal side, as of the beginning of 2001, sections 403 and 201(n) of the Federal Food, Drug, and Cosmetic Act (the act) governed the labeling of foods and defined false and misleading labeling. *Guidance for Industry* released in January 2001 by the U.S. Food and Drug Administration (U.S. FDA) specified that “the fact that a food or its ingredients was produced using bioengineering is a material fact that must be disclosed under sections 403(a) and 201(n) of the act” and “[does] not require special

⁶ Other papers inquiring into labeling of (food safety) credence attributes include Segerson (1999); Starbird (2000); Marette, Bureau, and Gozlan (2000); McCluskey (2000); Miller and VanDoren (2000); and Feddersen and Gilligan (2001).

labeling of all bio-engineered foods” (FDA’s *Guidance for Industry*).⁷ As a result, labeling indicating the GM content of food products was a voluntary action adopted by some food producers.

Cases of false labeling in organic food markets are widely documented (e.g., see McCluskey 2000 and references therein). Similarly, “non-GMO” or “GMO-free” types of labels may inaccurately reflect the percentage of modified genes contained in a food item. For example, according to Callahan and Kilman (2001), about 40% of soybean DNA in a sample of “non-GMO” veggie bacon produced by Yves Veggie Cuisine, a Canadian maker of vegetarian dishes, was found to be genetically modified. These authors document a number of other cases of misrepresentative “GMO-free” labeling.

6. Ex Ante and Ex Post False Labeling

Generally, two distinct approaches can be used to define false labeling (Wittman 1977). An “ex ante” definition of false labeling, which is the primary definition used in this paper, is more restrictive. It states that a label is false if a food item is labeled as non-GMO without the exact knowledge that the item has GM content not exceeding the tolerance level. Therefore, even if a product happens to be GMO free, this kind of labeling is considered an act of cheating. According to the “ex post” definition, a product is falsely labeled as non-GMO only if it is revealed to possess a GM substance. Both definitions have their virtues and drawbacks. On one hand, the “ex post” definition is more internally consistent with the assumption of risk-neutral consumers which is adopted in this paper.⁸ On the other hand, the “ex ante” definition is likely to be more appealing in real world situations.⁹ It will be shown that the recommendations for anti-false labeling policies are likely to differ somewhat depending on the definition used.

⁷ Other countries have taken an opposite stance on this issue. For example, in 2001 the UK rules stated that GM food had to be labeled unless neither protein nor DNA resulting from genetic modification was present.

⁸ For example, see Segerson (1999) for a discussion of the use of this assumption in food safety models.

⁹ Even though an individual food item derived from non-IP ingredients may be correctly labeled as non-GMO, on the average, non-IP retailers who label their products as non-GMO are committing a fraud.

And so, in the second part of the paper, I extend the choices available to retailers to include false labeling.¹⁰ When the penalty for false labeling is low and labels are difficult to verify, some non-IP processors may label their products as non-GMO. The possibility of making false non-GMO claims effectively puts a cap on the revenues earned by the IP non-GMO food suppliers. I derive some interesting comparative statics pertaining to the relationship between the extent of false labeling and the expected penalty.

Model

In the model, I identify three points of interest in time: 1, 2, and 3. The farmers plant two varieties of crops, GMO (G) and non-GMO (N) at time 1. At time 2, the retailers buy the crops from the farmers and process them into final food products whose identity (N or G) is not known to consumers unless products are certified as IP.¹¹ IP type N and non-IP (unlabeled) food items are sold to consumers at time 3. The timing of production and consumption decisions is illustrated in Figure 1.

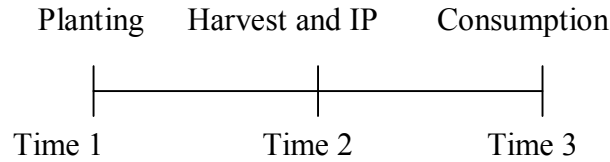


Figure 1. Timing of events

Demand Side

Following Saak and Hennessy, all consumers are held to have unit demands and consume, at most, one type of (food) product. A type ε consumer's preferences for consumption of one unit of type N food, $t_N = 1$, or a unit of type G food, $t_G = 1$, are given by

$$U(t_N, t_G, \varepsilon) = \begin{cases} 1, & \text{if } \{t_N, t_G\} = \{1, 0\} \\ \varepsilon, & \text{if } \{t_N, t_G\} = \{0, 1\} \end{cases}$$

¹⁰ This approach fits broadly into the literature on credence goods and the equilibrium amount of fraud pioneered by Darby and Karni (1973).

¹¹ To focus on the market differentiation between the two varieties, food processing is taken to mean only preserving (or not preserving) food variety.

That is, any consumer derives unit gross utility from consuming a unit of N. The utility derived from consuming a unit of G differs across consumers and is equal to the consumer's type $\varepsilon \in [0,1]$.¹² The distribution of types among the consumers is given by a continuous strictly increasing cumulative distribution function $H(\varepsilon)$, where function $H(0) = 0$ and function $H(1) = 1$. An inverse of function $H(\varepsilon) = z$ always exists: $\forall z \in [0,1]$, and is given by $\varepsilon = J(z)$. Furthermore, we assume that the consumer's utility is quasi-linear in a numeraire good.

Consumers cannot differentiate between type N and G food products unless they are labeled as such. Since labeling is voluntary, only IP type N products are labeled. For now, false labeling is assumed away. However, if a product is not labeled and not all of variety N is processed through IP, consumers do not know whether the food is of type N, or of type G. Type ε consumers who consider purchasing an unlabeled product rationally estimate their gross utility of consumption as

$$1 \cdot \Pr(\text{type N} \mid \text{Unlabeled}) + \varepsilon \cdot \Pr(\text{type G} \mid \text{Unlabeled}).$$

Under certain conditions on the inverse demand $J(\cdot)$, a consequence of this assumption is the price premium for IP type N food that is an (locally or globally) increasing function of the supply of IP type N products.

Supply Side

Both the raw crop and food retail markets are perfectly competitive. At time 1, the homogenous and risk-neutral farmers allocate a fixed stock of land between the two varieties N and G. The stock of land is normalized to 1 and per acre yield is constant—invariant across varieties—and is also normalized to 1. The share of land planted to variety N is given by $x \in [0,1]$. Then the crop of variety N (G) available at harvest time 2 is given by x ($1-x$). Unit production costs of varieties N and G are given by c^n and c^g , where $c^n > c^g$.¹³

At time 2, after the harvest, farmers sell their crops to the fixed number of homogenous and risk-neutral retailers and receive farm-gate prices f^n and f^g for varieties

¹² Observe that this means that all consumers (*weakly*) prefer type N food.

¹³ The cost differential may, in part, arise because of costly on-farm segregation of variety N.

N and G, respectively.¹⁴ While some retailers decide to supply the IP type N food, others choose not to invest in the IP program. A share of variety N $s \in [0, x]$ processed through IP is established at time 2. The unit cost of IP is given by $c(x, s)$, which is continuous, twice differentiable in each argument function and is subject to the two types of production externalities discussed previously. We hold that the unit cost of IP declines in the supply of variety N, $c_x(x, s) \leq 0$, and increases in the share of identity preserved variety N, $c_s(x, s) \geq 0$ where the subscripts denote differentiation.¹⁵

I do not consider the possibility of a “contaminated” non-biotech variety due to cross-pollination between GM and non-GM varieties. Also, only expensive tests (a part of the IP costs) or costly monitoring of the grower’s production methods can be used to ascertain the crop variety. Hence, the retailers who do not invest in the IP program do not know what crop variety they bought from the farmers.¹⁶ This implies that the non-IP suppliers do not differentiate between the two crop varieties and always purchase the cheaper one.

The cost of IP at time 3 is prohibitively high. Therefore, those retailers who do not invest in the IP program do not know with certainty the GM content of their final food products. At time 3, retailers sell labeled type N (IP) and unlabeled (non-IP) food products to consumers for prices p^l and p^u , respectively. Neither retailers nor farmers can distinguish between the consumers of different types, and no arrangements between the suppliers and consumers can be made prior to time 3.

Game Tree of Market Differentiation

As will become clear in what follows, in general, an extensive-form game for the market differentiation between varieties N and G looks as shown in Figure 2. In Figure 2, the last five rows of the market differentiation game tree are the payoffs (i.e., per unit profits) to

¹⁴ The possibility of contractual arrangements between variety N growers and retailers will be discussed later in the paper.

¹⁵ Note that it is assumed that the unit cost of on-farm segregation, c^n , is not subject to production externalities, i.e., $c^n(x) = c^n \forall x$. Relaxing this simplifying assumption will not change the central message of the paper.

¹⁶ To focus on the information asymmetry at the consumer’s level, assume that the farmers do not attempt to pass variety G crop off as variety N when selling their crop to the IP retailers. However, the retailers who do not invest in the IP program gain nothing in terms of the probability of supplying a type N product by

growers and retailers. As will be explained, there can be multiple equilibrium values of s . In an equilibrium with $s < x$, the price of variety N, f^n , is bid down to f^g because non-IP retailers do not differentiate between the two varieties. However, there must be a strictly positive probability, π , that equilibrium with $s = x$ takes place because $f^n > f^g$ only if IP retailers buy *all* of variety N. Otherwise, variety N growers never receive a premium, and hence, no variety N is planted.¹⁷

To analyze this game, I will employ the concepts of Nash equilibrium and subgame perfect Nash equilibrium. Subgame perfect Nash equilibrium will be found by backward induction. Since all players act competitively, this simply amounts to determining the competitive (Nash) equilibrium at each stage of the game given that players *correctly anticipate* the equilibrium outcomes in the following stages.

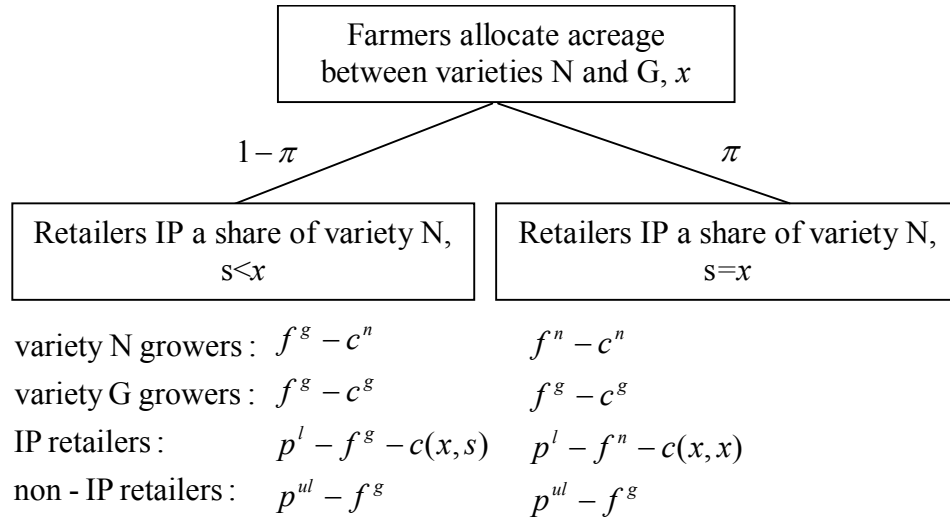


Figure 2. Two-stage game of market differentiation

Retail Market at Time 3

At the end of time 3, the share of variety N, x , and the share of IP products, s , are fixed. By the law of large numbers, the probability that a non-IP food product belongs to variety G, q , can be found as

purchasing variety N crop. For example, this may be the case when the farmers are truthful with the IP retailers but always try to take advantage of the non-IP retailers.

$$(1) \quad q(x, s) = \Pr\{\text{type G} \mid \text{Unlabeled}\} = (1 - x)/(1 - s).$$

Then, a type ε consumer utility is given by

$$(2) \quad U(\varepsilon) = \max[1 - p^l, (1 - q) \cdot 1 + q \cdot \varepsilon - p^{ul}].$$

The threshold type ε^* that is indifferent between purchasing a unit of the labeled and unlabeled product is determined by

$$(3) \quad \varepsilon^* = 1 - p/q,$$

where $p = p^l - p^{ul}$. Observe how the price differential, p , that governs the consumer choice between the two products is “marked up” by the probability that a non-IP product belongs to type G food, q . Equilibrium in the retail market is then given by

$$(4) \quad H(\varepsilon^*) = s,$$

where the superscripted “*” denotes the equilibrium values. Substitute (7) into (8) and take the inverse to obtain

$$(5) \quad p^* = q(x, s)(1 - J(s)).$$

The right-hand side (RHS) of (5) may be non-monotone in s under certain assumptions on the curvature of $J(s)$. The price premium paid for type N food is a product composed of two terms: $q(x, s)$ and $1 - J(s)$, so that a small increase in s has, in general, an ambiguous effect. On one hand, as the share of IP products rises, the supply of non-IP products becomes less valuable because $q(x, s)$ increases with s . On the other hand, the inverse demand for type N food decreases with s . Intuitively, these are the two forces that compete with each other.

Raw Crop Market and Segregation at Time 2

At time 2, the unit profit from selling the IP (labeled) product is given by

$$(6) \quad p^l - c(x, s) - f^n,$$

while the unit profit from selling a non-IP (unlabeled) product is given by

$$(7) \quad p^{ul} - f^g.$$

¹⁷ For clarity, Figure 2 depicts the game-tree when only two equilibria exist.

At time 2, the share of variety N processed in isolation from variety G adjusts until the profit from IP processing is equated to the profit from supplying products with an unknown GM content. Equating the profit earned by IP retailers, (6), with that accrued to non-IP retailers, (7), and substituting the time 3 equilibrium price premium, (5), yields the following conditions describing the market equilibrium at time 2:

$$(8a) \quad q(x, s)(1 - J(s)) \leq c(x, s), \quad (f^n - f^g)^* = 0, \quad \text{if } s^* = s < x,$$

$$(8b) \quad 1 - J(x) = c(x, x) + (f^n - f^g)^*, \quad \text{if } s^* = x.$$

Note that $f^n < f^g$ is impossible in equilibrium since there would be an excess supply of variety G crop. Also note that if $s^* < x$ then it must be that $f^n = f^g$. Otherwise, there will be an excess supply of variety N crop. Also, if $s^* = x$ in equilibrium at time 2, then it must be the case that $f^n \geq f^g$.

In general, when (8a) holds with equality, it can have multiple solutions. By inspection, the following lemma that gives sufficient conditions for the existence of multiple equilibria is derived.

LEMMA 1. *For any $x \in (0, 1)$ there are at least three equilibrium values of IP: $s^* = 0$, $s^* \in (0, x)$, and $s^* = x$ if $1 - x < c(x, 0) < c(x, x) < 1 - J(x)$.*

In what follows, the equilibrium with $s^* = 0$ is dismissed. Let $\{s_i\}$, $i = 2, \dots, N$ where $s_1 = x$ denotes the set of equilibrium values of s^* , i.e., solutions to (8a). In light of the lemma, make the following assumption.

ASSUMPTION 1. *The share of variety N processed through IP, s^* , is a random variable with the discrete probability distribution $s^* = s_i$ with probability π_i , $i = 1, 2, \dots, N$, $\sum_{i=1}^N \pi_i = 1$.*

Then the expected unit cost of IP is given by $E[c(x, s^*)] = \sum_{i=1}^N \pi_i c(x, s_i)$ where the expectation operator is taken with respect to s^* . I now proceed to characterize equilibrium at planting.

Equilibrium at Planting Time 1

At time 1, the acres sown to variety N adjust until the expected net revenues per acre from planting variety N and G are equal:

$$(9) \quad E[f^n - c^n] = E[f^g - c^g].$$

In other words, the expected price premium paid for variety N at harvest must be equal to the production cost differential delivered by variety G, $c^n - c^g = c^f$. Using (8b), obtain the following condition characterizing the equilibrium value, x^* :

$$(10) \quad (1 - J(x^*) - c(x^*, x^*))\pi_1 = c^f.$$

To guarantee the uniqueness of x^* , also requires the following assumption:

ASSUMPTION 2. $c_s(x, x) \geq -c_x(x, x) \quad \forall x \in (0,1)$.

Under assumption 2, for fixed π_1 , the left-hand side (LHS) of (10) is decreasing in x . Now the IP cost efficient (IPCE) competitive equilibrium can be defined.

IP Cost Efficient Competitive Equilibrium

The following definition demonstrates how the considerations of the production cost efficiency of IP in a competitive equilibrium may lead to optimal randomization between processing all and a part of variety N.

DEFINITION 1. *The IPCE equilibrium in the market-differentiation game is the pair (x^*, s^*) such that*

$$(1 - J(x^*) - c(x^*, x^*))\pi_1 = c^f; \quad (\text{equilibrium acreage allocation at time 1})$$

$$q(x^*, s_i)(1 - J(s_i)) = c(x^*, s_i); \quad i = 2, \dots, N \quad (\text{equilibria with low level of IP at time 2})$$

$$E[c(x^*, s^*)] = \min_{\pi_i} \sum_{i=1}^N \pi_i c(x^*, s_i); \quad (\text{expected unit IP cost is minimized})$$

where N is the number of distinct solutions $\{s_i\}$ taking x^* as given.

In general, determining an IPCE requires solving a non-trivial constrained optimization problem.¹⁸ Here the focus is on the equilibrium where the cost structure of IP dictates that s^* “mimics” the behavior of a non-degenerate random variable. The following provides sufficient conditions such that this happens.¹⁹

RESULT 1. *Let the condition in lemma 1 hold. Then $\pi_1 < 1$ in the IPCE equilibrium if $c_x(x, x) + c_s(x, x) = 0 \quad \forall x \in (0,1)$.*

The condition in result 1 precludes the variation in the supply of variety N at harvest from affecting the cost of IP when all of the variety is IP processed. The next result characterizes the equilibrium probability distribution of s^* when randomization is optimal.

RESULT 2. *The IPCE equilibrium probability distribution of s^* is in two modes:*

$$s^* = \begin{cases} x^*, & \text{with probability } \pi \\ s_1, & \text{with probability } 1-\pi \end{cases},$$

where $s_1 = \min_i \{s_i\}$.

The expected unit cost of IP is minimized when the share of IP oscillates between the lowest and the highest equilibrium shares of IP. This is so because $c_s \geq 0$ is assumed. So far the optimal probability distribution of s^* has been considered, taking for granted that competitive markets can always “support” the randomization. Relaxing this assumption is the subject of the next section.

¹⁸ The rather technical conditions for the uniqueness of IPCE competitive equilibrium will not be stated in the text.

¹⁹ All the proofs not provided in the text are contained in the Appendix.

Fixed Probabilities

Hypothetically, the IPCE equilibrium can be supported if growers and retailers observe some random event and have the equilibrium share of variety N processed through IP depend on the realizations of this event. However, due to the difficulties in coordination across the two markets, the optimal IPCE probability distribution of s^* may not be sustainable. Consider here a version of a “constrained” IPCE competitive equilibrium where the probabilities, π_j , $j = 1, \dots, N$, are taken as given.

Then the question arises how the supportable probability distributions of s^* , with $E[s^*]$ fixed, can be compared in terms of the expected unit cost of IP. Observe that the fixity of π_i implies that x^* is fixed as well. However, it no longer holds that $c_s(x, s) \geq 0$. Then, under plausible conditions there may be an even larger variety of equilibrium shares of IP $\{s_i\}$, $i = 2, \dots, M$ where $N < M$. To provide a partial ordering on this set, pick two alternative candidates $\{s_i\}$ and $\{s'_i\}$, $i = 1, 2, \dots, N$, where both sequences are ordered in a decreasing order. Note that $s_1 = s'_1 = x^*$. The following definition is required.

DEFINITION 2. (Cheng, 1977) Let $\sum_{i=1}^k \pi_i s_i \leq \sum_{i=1}^k \pi_i s'_i$ for $k = 1, 2, \dots, N - 1$, and $\sum_{i=1}^N \pi_i s_i = \sum_{i=1}^N \pi_i s'_i$. Then sequence $\{s_i\}$ is said to be p -majorized by sequence $\{s'_i\}$, written as $\{s_i\} \prec_\pi \{s'_i\}$, for arbitrary $\pi_i \in (0, 1)$.

The notion of p -majorization compares two sequences in terms of “weighted” dispersion. By Corollary A.7 in Marshall and Olkin (1979, p. 421), $V(s_1, s_2, \dots, s_N) = \sum_{i=1}^N \pi_i c(x, s_i)$ is a generalized Schur-convex (Schur-concave) function, and it increases (decreases) in the p -majorization order when $c(x, s)$ is convex (concave) in the second argument.

RESULT 3. For arbitrary probabilities π_i let $\{s_i\} \prec_{\pi} \{s'_i\}$. Then $E[c(x^*, s)] \leq (\geq) E[c(x^*, s')]$ as $c_{ss}(x, s) \geq (\leq) 0 \quad \forall x \in (0, 1), \quad \forall s \in (0, x)$.

Result 3 is, essentially, based on a discrete version of the notion of mean-preserving spread (contraction) of a probability distribution. Thus, the expected unit cost of IP decreases (increases) under a more “dispersed” distribution of equilibrium shares of IP if the unit cost of IP, $c(x, s)$, is a convex (concave) function of s .

The following section discusses some assumptions necessary for the existence of the IPCE and “constrained” IPCE competitive equilibrium.

Other Reasons for the Existence of Multiple Equilibria

In the preceding analysis, multiple levels of s^* that leave retailers indifferent between processing or not processing through IP exist, in part, because the price premium, p , is a (locally) increasing function of s . On the other hand, this condition is neither sufficient nor necessary when there are positive production externalities of the second type in IP processing. While it seems likely that $c(x, s)$ is decreasing in the first argument and increasing in the second, other situations are possible. As was discussed in the introduction, for example, due to economies –of scope and specialization, the industry-wide unit cost of IP may fall when the share of IP processing rises. Some recent improvements in GMO testing procedures illustrate how an emerging demand for IP technologies can lower the cost of production.

If such positive production externalities do pertain to the IP sector, then the presence of imperfect information that leads to the non-monotonicity of the price premium is no longer necessary to generate the multiple equilibria. In other words, the assumption that IP preserves a credence quality of a product can be dispensed with. Then the equilibrium conditions that determine the level of IP, s_i , that are less than the supply of the preferred variety, x^* , are given by

$$1 - J(s_i) = c(x^*, s_i), \quad i = 2, \dots, N$$

$$(1 - J(x^*)) - c(x^*, x^*)\pi_1 = c^f,$$

where $s_i < x^*$ and $c(x^*, s_i) > c(x^*, x^*)$.

On the other hand, contractual arrangements between growers and retailers may provide another vehicle for reducing IP costs. Producers' choice to plant and supply IP variety N through contracts rather than using "spot" market transactions is considered next.

Contractual Arrangements

To fix ideas, assume that a contract agreement specifies the premium paid to variety N grower upon the delivery. Let the unit cost of IP processing under contract be given by c^c . Hold that for each $x \in (0,1)$ there exists $\hat{s} \in (0,x)$ such that $c(x,s) \leq c^c$ for all $s \in (0,\hat{s})$ and $c(x,s) \geq c^c$ for all $s \in [\hat{s},x]$. In other words, the unit cost of IP processing under contract is higher when the share of IP is small. However, the situation is reversed when the share of IP is high. This may happen when the processing under contract pays off when the supply of variety N is tight relative to demand due to, say, increased search and transportation costs associated with buying variety N in the cash market.

Then, at time 1, retailers face three alternative strategies: (1) supply IP products without contracts with growers, (2) supply IP products using contracts with growers, and (3) supply non-IP products. Similarly, growers can choose among three options: (1) plant variety N and sell it in the spot market, (2) plant variety N under contract, and (3) plant variety G. The model holds that planting variety N under contract does not impose on growers any additional costs. This, of course, implies that risk-neutral growers using contracts will demand a premium no less than the expected premium offered in the spot market.

Assume that the expectation of the unit profits from all three activities taken with respect to random variable s^* adjusts so that retailers and growers are indifferent between the three strategies.²⁰ This can be stated as follows:

$$E[p^l - c(x^*, s^*) - f^n] = E[p^l - c^c - f^n] = E[p^{ul} - f^g], \text{ or}$$

$$(11) \quad c^c = E[c(x^*, s^*)].$$

Even though the share of IP retailers who use contracts is not determined, assume that it is in the interval $(0, \min_i \{s_i\})$.²¹ Therefore, the presence of contractual arrangements establishes an upper bound on the expected unit cost of IP.

The previous analysis is based on the assumption that non-GMO labeling is always accurate. Then there is only one source of imperfect information: consumers do not know the exact GM content of non-IP (unlabeled) products. The possibility of falsifying the non-GMO certification process leads to information asymmetry where consumers know less than retailers do about the likely GM content of a labeled product. The rest of the paper explores the mechanics of the market differentiation when both sorts of imperfect information are present.²²

False Labeling and Penalty for False Labeling

Now hold that non-IP food products can be labeled as type N, and so false labeling can take place. Both a non-GMO identity-preserved (IP) product and an uncertified product can be labeled as variety N at no cost. The share of the labeled food products is given by $l \in [s, 1]$ so that, in addition to the IP type N food, some processors may market food products with an unknown GM content under a non-GMO label. If discovered, false labeling is subject to a penalty, F , and legal liability. For concreteness, hold that only ex post false labeling can be detected, i.e., only food items labeled as type N but *actually* belonging to type G can be spotted.²³ Further assume that the government or consumer groups have a success rate

²⁰ Note that if all of variety N is grown under contracts, i.e., strategy (1) is uniformly abandoned, then no uncertainty with respect to s^* remains. The focus here is on the case when all three marketing strategies co-exist.

²¹ Note that the common beliefs by growers and retailers about the likelihood of a particular outcome may give rise to an equilibrium probability distribution.

²² The model to follow can be easily modified to consider the case when non-IP (unlabeled) products cannot be of type N but non-GMO labels can be false. This can be the case when the purity level required for a product to pass a non-GMO test is *very* high. Then the presence of GM substance in the non-IP products is inevitable and the approximation of the probability that a non-IP product is of type N by $1 - q(x, s)$ cannot be used.

²³ Hold also that IP retailers will never be accused of false labeling. In other words, a law enforcement (monitoring) agency can only commit a type I error: failing to detect a fraud; but it cannot commit a type II error and accuse an innocent retailer. This assumption is relaxed in a number of papers (e.g., see White and Wittman 1983, Kaplow and Shavell 1994, and Kaplow and Shavell 1996).

$\alpha \in [0,1]$ ²⁴ of discovering such cases of cheating. Then the probability that a retailer will be caught is calculated as $\alpha q(x,s)$, and the expected penalty is given by²⁵

$$(12) \quad \Pr(\text{Fraud is Detected} \mid \text{non - IP retailer}) \cdot F = q(x,s)\bar{F},$$

where $\bar{F} = \alpha F$.

Assume that α and F are set at the beginning of time 1 and are used by the food manufacturers to estimate the expected fine.

Consumer Behavior When Labels Can Be False

In general, there are two ways in which a non-GMO labeled food product can turn out to be type N. It can be IP from the beginning and then there is $q_a = s/l$ chance that the label is not false.²⁶ Or, even though the label is false and the IP guidelines were not followed, the product can be type N food anyway. The probability of the latter is equal to $[1 - q_a] \cdot [1 - q]$. The last expression implies that two events happen. First, the label is ex ante false. Second, given that the label is a fraud, it can happen that variety N crop was “accidentally” used to derive that product. The probability that a labeled product truly belongs to type N food is then given by

$$\Pr(t_N \mid \text{Labeled as non - GMO}) = q_a + [1 - q_a] \cdot [1 - q].$$

The probability that a labeled product is a type G food is given by

$$\Pr(t_G \mid \text{Labeled as non - GMO}) = [1 - q_a] \cdot q.$$

This expression has a similar interpretation. As previously noted, the probability that an unlabeled product is, in fact, of type N is given by $1 - q$. The only piece of information conveyed by the absence of a label is the fact that the product is, certainly, non-IP. Observe

²⁴ Parameter α can be thought of as the probability of detecting a (ex post) false label by the monitoring agency when the label is false (ex post). The probability of detection is an important policy variable but it is taken to be exogenous during most of the analysis. One could hypothesize that the optimal monitoring effort can be a function of the share of ex ante false labels. The model will not be complicated in this dimension. For example, an inquiry into the relationship between enforcement costs and the optimal magnitude and probability of fines is presented in Polinsky and Shavell 1992.

²⁵ Due to the large scale of their operations, retailers also are held to rely on the law of large numbers when evaluating the probability of having a pure type N food product.

²⁶ Note that q_a is also the share of labeled products processed following the IP practices.

that it is always the case that $\Pr(t_N | \text{Labeled}) > \Pr(t_N | \text{Unlabeled})$, i.e., the non-GMO labeled product is always more valuable to consumers.

Even though consumers have no way of telling a true label from a false one without a costly verification procedure, they rationally anticipate that a label can be false. Then, a type ε consumer utility is given by

$$(13) \quad \max[\{q_a + (1 - q_a)(1 - q)\} \cdot 1 + (1 - q_a)q \cdot \varepsilon - p^l, (1 - q) \cdot 1 + q \cdot \varepsilon - p^u].$$

In the manner of (3), the threshold type ε^* that is indifferent between purchasing a unit of the labeled and unlabeled product can be found as

$$(14) \quad \varepsilon^* = 1 - p/[q_a q].$$

Observe that now the surplus of consumers who buy type N food is “marked up” by both the probability that a labeled product is IP and by the probability that a non-IP product belongs to type G.

Equilibrium Supply of Type N Labeled Product

Because consumers can only differentiate between labeled and unlabeled products, equilibrium in the retail market is given by

$$(15) \quad H(\varepsilon^*) = l.$$

Then the equilibrium price premium can be found as

$$(16) \quad p^* = q_a(s, l)q(x, s)(1 - J(l)).$$

Observe that (5) is a particular case of (15) with $l = s \quad \forall s$, i.e., when no false labeling occurs. Turning to the supply side, the expected (average) unit profit accrued to non-IP retailers who label their products as type N is given by

$$(17) \quad p^l - q(x, s)\bar{F}.$$

The equilibrium amount of the labeled product, l^* , will adjust until non-IP retailers are indifferent between marketing their products as type N or non-IP:

$$(18a) \quad p^l - q(x, s)\bar{F} = p, \text{ if } l^* > s;$$

$$(18b) \quad p^l - q(x, s)\bar{F} < p, \text{ if } l^* = s.$$

Substituting (16) into (18), we find the equilibrium price premium for the labeled food:

$$(19) \quad p^* = q(x, s^*) \min[1 - J(s^*), \bar{F}],$$

where $q_a(s^*, l^*)(1 - J(l^*)) = \bar{F}$, if $l^* > s^*$, and we take that $\bar{F} < 1$ since otherwise the prospect of getting caught and fined completely eliminates any fraudulent labeling.

And so, l^* “follows” the probability distribution of s^* because it depends on which level of IP is realized. Because each realization of s^* , s_i is, in general, a function of \bar{F} , the effect of a small increase in \bar{F} on $l^* = l(s_i(\bar{F}), \bar{F})$ can be decomposed into the “direct” effect, $\partial l^* / \partial \bar{F}$, and the “indirect” effect, $[\partial l^* / \partial s_i][\partial s_i / \partial \bar{F}]$. Also, note that the condition for the profitability of false labeling, $1 - J(s_i) \geq \bar{F}$, depends on the monitoring intensity, α , but it does not depend on the likelihood of being caught cheating, $q(x^*, s_i)$. This is so because of the assumption that only the “ex post” false labeling can be detected. Consequently, the probability that a non-IP product belongs to variety G affects not only the price premium but also the expected fine (see [12]).

The game played at the first two stages of the market-differentiation game remains essentially unchanged in the presence of false labeling. In light of (19), definition 1 can be regarded as a special case of false labeling equilibrium with $1 - J(s_i) < \bar{F}$ for all $i = 1, \dots, N$.

DEFINITION 3. Given probabilities π_i , $i = 1, \dots, N$ where $\pi_1 > 0$, equilibrium in the market-differentiation game with false labeling is the tuple $(x^*, s_2, \dots, s_N, l_1, \dots, l_N)$ such that

$$(\min[1 - J(x^*), \bar{F}] - c(x^*, x^*))\pi_1 = c^f \text{ (acreage allocation at time 1);}$$

$$[(1 - x^*) / (1 - s_i)]\bar{F} = c(x^*, s_i) \text{ (equilibrium with low level of IP at time 2);}$$

$$[s_i / l_i](1 - J(l_i)) = \bar{F}, \text{ if } 1 - J(s_i) \geq \bar{F} \text{ (false labeling is profitable);}$$

$$\text{and } l_i = s_i \text{ otherwise (false labeling is unprofitable at } s^* = s_i);$$

where $s_i \in (0, x^*]$, and $l_i \in [s_i, 1)$ for $i = 1, \dots, N$.

Note that it is not a requirement that false labeling be profitable at all levels of IP. Clearly, if false labeling is profitable at $s^* = x^*$ then it must be profitable at $s^* = s_i < x^*$ as well, but

not vice versa. Next is an investigation of some of the properties of false labeling in a partial equilibrium at time 3.

Effects of Penalty and the Level of IP on False Labeling in Partial Equilibrium

Conditional on the realized level of IP, s_i , measure the extent of false labeling according to the share of the “ex ante” false labels, W as:²⁷

$$(20) \quad W(s_i, l_i) = 1 - q_a(s_i, l_i).$$

Analyzing (20), a useful finding is obtained.

RESULT 4. *In partial equilibrium, the share of falsely labeled supply W*

a) decreases when the level of IP increases;

b) increases (decreases) when \bar{F} increases if $\partial s_i(\bar{F}) / \partial \bar{F} < (\geq) (-1) / J'(l_i)$.

In other words, two complementary means, boosting the level of IP and adjusting the expected penalty, are available to combat false labeling. However, an increase in \bar{F} , *anticipated* by agricultural producers, may lead to a lower equilibrium realization of s^* or x^* and therefore may actually *increase* the realized share of false labels. Given a particular realization of s^* , s_i , the equilibrium share of falsely labeled supply, $W(s_i, l(s_i))$, increases as a result of a higher expected penalty if the level of IP responds negatively and such a response is sufficiently strong. An increase in \bar{F} has two effects on the share of false labels, $W(s_i(\bar{F}), l(s_i(\bar{F}), \bar{F}))$. The “direct” effect, $\partial l_i / \partial \bar{F}$, is operative at *time 3*, and it unambiguously (weakly) lowers l_i . The “indirect” effect works its way through a change (either positive or negative) in the level of IP *at time 2*, $\partial s_i / \partial \bar{F}$. If $s_i(\bar{F})$ responds relatively more (in absolute terms) to a small increase in \bar{F} than the inverse aggregate demand, $J(l_i)$, responds to a small increase in l_i , then the negative indirect effect dominates

²⁷ To detect ex ante false labeling, the adherence to the IP production practices at various stages of food processing needs to be verified.

and the share of false labeling will rise at time 3. On the other hand, if s_i increases when \bar{F} increases, then the share of false labels, given that $s^* = s_i$, must always fall at time 3.

Illustration of Effects of Penalty on Expected False Labeling

From (20), the expected (or average) amount of the “ex ante” fraud is then given by

$$(21) \quad E[W(x^*, s^*)] = 1 - \sum_{i=1}^N \pi_i s_i / l(s_i).$$

When the probability distribution of s^* is endogenous in IPCE equilibrium, determining how the expected share of false labels responds to an increase in penalty, $\partial E[W] / \partial \bar{F}$, becomes an arduous task. This is so because $E[W]$ is, potentially, a function of five endogenous variables: π_1^* , s_2 , x^* , and l_i where $i = 1, 2$. It can be shown that equilibrium IPCE values of π_1^* , s_2 , and/or x^* may either decrease or increase when \bar{F} increases. Leaving a comprehensive comparative statics analysis to the interested reader, I provide instead a simple example that illustrates both possibilities in the “contract” equilibrium.

EXAMPLE 1. Hold that both contractual and “spot market” forms of marketing variety N at harvest are used in false labeling equilibrium. Furthermore, specify the functional form of the unit cost of IP as follows: $c(x, s) = c^c - e$, if $s < x$, and $c(x, x) = c^c + e$. If (11) holds then it must be the case that $\pi^* = 0.5$. Hence, the equilibrium share of acres sown to variety N is given by $x^* = H(1 - c^c - e - 2c^f)$. Then the equilibrium where false labeling takes place at $s^* = s_2 > 0$ but not at $s^* = x^*$ is determined by

$$x^* = H(1 - c^c - e - 2c^f) \text{ (acreage allocation at time 1);}$$

$$[(1 - x^*) / (1 - s_2)] \bar{F} = c^c - e \text{ (equilibrium with low level of IP at time 2);}$$

$$[s_2 / l_2] (1 - J(l_2)) = \bar{F}, \text{ where } 1 - J(s_2) > \bar{F} \text{ and } l_2 > s_2 \text{ (false labeling at } s^* = s_2);$$

$$l_1 = x^* \text{ and } 1 - J(x^*) < \bar{F} \text{ (no false labeling at } s^* = x^*).$$

The equilibrium level of IP when not all of variety N is processed is given by

$$(22) \quad s_2 = 1 - \bar{F}(1 - x^*) / (c^c - e) \in (0, x^*).$$

Differentiating gives $\partial s_2 / \partial \bar{F} = -(1 - x^*) / (c^c - e) < 0$. Applying lemma 2 (part b), the expected share of false labels, $E[W]$, increases (decreases) when the expected penalty, \bar{F} , increases depending on whether $J'(l_2) \geq (<)(c^c - e) / (1 - x^*)$.²⁸

In example 1, $E[W]$ increases if the inverse demand schedule is sufficiently responsive to a small increase in the share of labeled products, l_2 . It is interesting to explore why, taking the supply of variety N, x^* , as given, the “low” level of IP, s_2 , increases when the penalty, \bar{F} , decreases (see [22]). Then, falsely labeling a non-IP product as type N appears more attractive (the so-called direct effect of a higher penalty on the profitability of false labeling). To bring down the incentive to exert dishonest behavior that dilutes the value of IP labeled products, IP retailers can be thought of as bumping up the probability that a falsely labeled product will be detected by raising the level of IP at time 2. Such “odd” behavior becomes more transparent once $q(x^*, s_2)\bar{F}$ is interpreted as the (average) cost imposed on non-IP retailers who falsely label their products at time 3.

In the next section, I investigate some consequences of pairing the ex ante goal with the ex post penalty. Keep in mind that the ex ante goal is to reduce the share of non-IP products labeled as variety N. The ex post penalty is a penalty that is imposed on non-IP retailers who were detected supplying labeled products belonging to variety G. One may wonder to what extent the results are driven by this peculiar pairing of the objective and the instrument. The goal of the next subsection is to demonstrate that the central message of this paper is not affected by that choice.

Ex ante Penalty for False Labeling

Imagine now that the government or a monitoring private agency has the authority to penalize not only ex post false labeling but also ex ante false labeling. The amount of the fine charged to non-IP retailers who are detected labeling their products as type N is denoted by F_a . Assume that the share of non-IP retailers who are spotted labeling their products as

²⁸ Also, sufficient condition of the form $J'(l) \geq (<)c / (1 - x^*) \quad \forall l \in [s_1, 1]$ can be used.

type N is given by $\beta \in [0,1]$. Furthermore, hold that retailers are subjected to both types of inspection, ex ante and ex post. Assume that retailers pay the larger of the two fines if both inspections were successful in detecting the fraud. Then the combined expected (or average) per unit penalty for cheating is given by

$$E[Penalty] = \alpha q_b (1 - \beta) F + \beta (1 - \alpha q_b) F_a + \alpha q_b \beta \max[F, F_a].$$

For example, consider the case when $F > F_a$. Then the expected penalty becomes

$$E[Penalty] = \alpha q_b (F - \beta F_a) + \beta F_a.$$

It can be shown that the share of ex ante false labels, $W(s_i, l_i)$, can either rise or fall when the level of segregation, s_i , increases depending on whether

$$(1 - x)J'(l_i) < (\geq) \beta F_a,$$

where l_i is now determined by $q_a(s_i, l_i)q(x, s_i)(1 - J(l_i)) = \alpha q(x, s_i)(F - \beta F_a) + \beta F_a$.²⁹

Also, in the manner of result 4, it can be shown that a higher level of IP has an ambiguous effect on the share of ex post false labels. Therefore, in general, policy recommendations implied by programs oriented to minimize ex ante and ex post false labeling need not coincide.³⁰

Concluding Remarks

This paper presents an efficiency explanation of some of the observed patterns of the emerging differentiation in the agricultural bulk commodity markets. The analysis can be extended in a number of ways. For example, any strategic behavior on the part of consumers prior to making consumption decisions was assumed away. The model also ignored any demand expansion or substitution effects that the presence of a cheaper GM food variety is likely to entail. In addition, the complex infrastructure of marketing channels and reputation incentives were completely left out of the model. A model that specifies the micro

²⁹ A detailed analysis of the effectiveness of the ex post type of penalty in the presence of the ex ante type of penalty is left to the interested reader. I merely point out here that it is not inconceivable that increases in the effectiveness (α or β) or the size of the penalties (F or F_a) will not bring about the reduction in the false labeling that they could, were one of the measures (partially) abandoned.

³⁰ The objective to minimize the share of ex post false labels, $[1 - q_a(s, l)] \cdot q(x, s)$, over s clearly is different from minimizing the share of ex ante false labels, $1 - q_a(s, l)$, over s .

foundations of segregation and IP technologies in commodity systems likely would provide further interesting insights and useful policy implications.

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Appendix

Proof of Result 1.

Note that the derivative condition implies that $c(x, x) = c \in (0, 1) \quad \forall x \in (0, 1)$. That being the case, the expected cost of IP in the no-randomization equilibrium is equal to c . Then one must show that there exist (x^*, s^*) such that $c > c(x^*, s_i)$. Observing that one can choose π_1 arbitrarily close to 1, and that $c(\bar{x}, s_i) \leq c(\bar{x}, \bar{x}) = c$, where $\bar{x} = H(1 - c - c^f)$ completes the proof.

Proof of Result 4. (a) $\partial W(s, l(s)) / \partial s \leq 0 \quad \forall s_1 \in [0, x]$.

Given the share of IP, s , the equilibrium share of labeled products, $l(s)$, is given by

$$(A1) \quad s(1 - J(l)) - l\bar{F} = 0.$$

Differentiating (A1) gives

$$(A2) \quad \frac{\partial l}{\partial s} = \frac{l}{s} \frac{\bar{F}}{\bar{F} + s \cdot J'(l)}.$$

Using (A2) and differentiating $W(s, l(s))$ yields

$$\frac{\partial W}{\partial s} = -\frac{\partial(s/l)}{\partial s} = \frac{s}{(l)^2} \frac{\partial l}{\partial s} - \frac{1}{l} = -\frac{1}{l} \frac{s \cdot J'(l)}{\bar{F} + s \cdot J'(l)} \leq 0.$$

(b) $\partial W(s(\bar{F}), l) / \partial \bar{F} \geq (<) 0$ as $\partial s(\bar{F}) / \partial \bar{F} < (\geq) (-1) / J'(l)$.

Differentiating the equilibrium share of false labels at time 3 with respect to \bar{F} gives

$$(A3) \quad \frac{\partial W}{\partial \bar{F}} = -([\partial s / \partial \bar{F}]l - s[\partial l / \partial \bar{F}]) / l^2.$$

From (A1),

$$(A4) \quad \frac{\partial l}{\partial \bar{F}} = \frac{l}{s} \frac{[\partial s / \partial \bar{F}]\bar{F} - s}{\bar{F} + sJ'(l)}.$$

Substituting (A4) into (A3) obtains

$$\frac{\partial W}{\partial \bar{F}} = -\frac{[\partial s / \partial \bar{F}]J'(l) + 1}{l(J(l) + \bar{F} / s)}.$$