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Four papers on agricultural finance and adoption of biotechnology

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CHAPTER 1. GENERAL INTRODUCTION

Explanation of Dissertation Format

The four papers comprising this thesis are entirely self-contained. They each have their own introduction, literature review, conclusions, and references. Nonetheless, they bear common features typical of microeconomic problems and often share analytical techniques used in formal analysis. The first two papers shed light on theoretical and empirical issues in finance and agricultural finance theory. The last two papers use a very similar modeling approach and explore several issues pertaining to adoption of biotechnology in agriculture.

Chapter 2 (Paper I) investigates financial measures of a projects' worth in a standard static setting where a time sequence of project's payments is fixed and known in advance. It is well known that net present value statistic may be non-monotone in the discount rate, and that there may be multiple internal rates of return when cash flows change sign more than once. We identify necessary and sufficient conditions such that net present value is monotone in the discount rate applied to evaluate a project. We also formulate a linear dominance condition on projects' cash flows sufficient to order a set of projects according to the internal rate of return criterion.

Chapter 3 (Paper II) develops a firmer understanding of the economics underlying the relationship between rental rates sensitivity to output price and land quality. The issue of how land price variability depends on distance to market has been of interest to agricultural economists for a long time. We extend the previous analysis by developing a more detailed theoretical foundation and providing some new empirical evidence to illustrate our findings. Using two measures of land quality: distance to market and yield productivity, we identify conditions on the production technology such that rental volatility varies in a monotone manner with land quality. To estimate these relationships empirically, we use county level data on Iowa cash rents collected over the period from 1994 to 2001. Our estimation results allow us to reject the null hypothesis of an inverse relationship between land quality and rental volatility with respect to commodity prices.

Chapter 4 (Paper III) highlights the role that uncertain consumer acceptance of genetically modified (GM) crop varieties may play in production decisions. We seek to explain the negative shift in acres sown to GM seed varieties in planting year 2000 as a result of a reduction in information available to growers at planting. Also, it is conjectured that growers make their acreage allocation decisions based on signals that inform them about the nature of post-harvest demand. We identify the types of signals that growers prefer to receive and we show how a more informative decision environment can affect the types of market equilibrium that emerge.

Chapter 5 (Paper IV) focuses on information asymmetry, where producers know more about their production practices than consumers, and voluntary labeling decisions. We develop a model of the market differentiation between GM and non-GM food varieties in a production environment where acreage allocation stage is followed by costly segregation between the two varieties. Having observed high demand for non-GM food variety, some food processors may falsely label their product as non-GM. We find that, contrary to intuition, the amount of fraud may not fall as a result of enhanced monitoring efforts, higher penalties, or a rebate on the cost of the investment in the segregation. In part two of the paper, the uncertainty about consumer acceptance of GM foods, penalty, and segregation costs is introduced. The effects of an increase in uncertainty on the level of segregation and acreage allocation are explored. We find plausible conditions such that the level of segregation and acres sown to non-GM variety fall when there is an increase in uncertainty at harvest and at planting.

CHAPTER 2. WELL-BEHAVED CASH FLOWS

A paper published in Economics Letters[1]

Alexander Saak and David Hennessy

Abstract

Internal rate of return and net present value statistics for evaluating projects may display anomalous behavior when cash flows change sign more than once. We identify necessary and sufficient conditions such that these anomalies are precluded. We also identify a linear dominance condition on payoffs sufficient to order internal rates.

1. Introduction

Let the net cash flow from a project be $g(t)$ at time t. Assuming a strictly positive time invariant rate of discount, $r \in \Re_{++}$, the project net present value is given by

$$N(r) = \int_0^\infty g(t) e^{-rt} dt \tag{1}$$

Solving $N(r) = 0$ gives the set of internal rate of return (IRR) solutions. It is well known that the set may have two or more elements, and this is one reason that the net present value (NPV) approach of fixing on an r value is often advocated as an alternative to be preferred over the IRR approach.[2] But Oehmke (2000) has pointed out that the same problem (multiplicity of roots) manifests itself in a different form under the NPV approach.[3] For $N(r) = 0$ to have multiple solutions, $N(r)$ must be non-monotone.

The problem is important because the IRR and, particularly, NPV asset evaluation approaches are central not only in the field of financial management but also in agricultural, environmental, and development economics. Many agricultural assets such as land,

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[1] Reprinted with permission of Economics Letters, 2001, 73, 81-88.

[2] See, e.g., Copeland and Weston (1988) for a primer on project valuation methods.

[3] In fact, the problem of non-monotonicity if NPV in the discount rate and its connection with the multiplicity of IRRs was recognized as far back as Samuelson (1937, p. 473).

machinery, or cattle require periodic investments making their NPV vulnerable to the posed problem. In addition, a conceptually similar problem appears in the analysis of the lease-purchase decision for agricultural assets (Ford and Musser). For example, sensitivity of the break-even lease payment to the discount rate hinges on the behavior of NPV of the streams of the depreciation and maintenance costs. An alternating pattern of inflows and outflows is also characteristic of natural resources and regional development programs.

One of the two themes of this paper is to follow Oehmke in seeking to establish conditions on the stream of cash flows such that $N(r)$ is monotone. For then we know the effect of an increase in a flat yield curve on the financial merits of a project. However, whereas Oehmke studies a discrete sequence of cash flows, where it is natural to invoke methods in the theory of polynomial root extraction, our analysis considers continuous cash flows and so we find it more appropriate to employ tools in real analysis. The second theme is to establish conditions under which one cash flow is possessed of a unique IRR that can be readily ranked with respect to the unique IRR of another cash flow.[4]

In the following section we provide a review of the relevant literature. Section 3 provides, and comments on, necessary and sufficient conditions to preserve monotonicity. Sufficient restrictions are imposed on the derivative properties of the cash flow function so that monotonicity is ensured in Section 4.[5] We conclude by studying good, or orderly, behavior within a set of projects that are to be compared by the IRR statistic. Specifically, we identify a simple class of cash flow shifts such that the unique IRR value for each project can be ranked upon inspection against those of other projects.

2. Literature Review

Characterizing a cash flow by the means of a single measure has been a long-lasting area

[4] For an alternative approach to obtaining the monotonicity, see Sen (1975). Also, see Promislow and Spring (1996) for a very general method for constructing IRR functions that are possessed of intuitively appealing properties.

[5] In closely related work, Bernhard (1980) has identified sufficient conditions under which a unique non-negative IRR exists.

of research. Amidst a variety of issues related to this topic, we single out the three distinct approaches to address some of the problems arising with the use of NPV and IRR to evaluate a cash flow and/or induce a ranking order on the set of cash flows.

By definition, an IRR may not be unique. Bernhard (e.g. 1980), along with others, focus on this difficulty and provided several computationally straightforward sufficient conditions guaranteeing the uniqueness of a non-negative IRR. Their analysis is carried out under the assumptions of perfect capital markets and certainty. Norstrom (1972) derived sufficient conditions (subsequently refined by Bernhard, deFaro, and others) based on the statistic referred to as the undiscounted accumulation of the cash flow from time 0 to time t and defined by: $G(t) = \int_0^t g(s)ds$. Most of this literature sought to establish a criterion for accepting a project by comparing the project's IRR with the market rate of interest.

Another strand of the literature on capital budgeting seeks to adapt the definition of IRR to obtain a more consistent and broadly applicable measure of a project's worth. One such approach to constructing an IRR was developed by Arrow and Levhari (1969). Here, it is assumed that a project can be truncated at any period and the truncation period is chosen so as to maximize the project's NPV (calculated over the initial periods preceding the truncation). Then they show that the resultant NPV (maximized over the optimal "stopping" time) is a monotone decreasing function of the time-invariant discount rate. Flemming and Wright showed that this result holds for a wide class of discount functions. The truncation method was subsequently enhanced to account for payments associated with truncating a project (Sen 1975).

An alternative approach to defining a unique (for a given interest rate on deposits) IRR is advocated by Teichroew et al. (1965a,b). They point out that the applied interest rate per period should differ depending on the sign of the outstanding balance. Namely, the investor earns the project's IRR when the outstanding balance is negative (the investor lends money to the project). When the balance is positive (the project lends money to the investor), a fixed deposit rate (the opportunity cost of capital) is earned. Then the project's IRR is the interest rate that ensures that the outstanding balance is zero at the end of the project's life. The authors demonstrate that such a procedure yields a unique and consistent IRR measure.

A recent paper by Promislow and Spring (1995) discusses and generalizes the previous work in this area and provides a rigorous mathematical treatment of the problem. Taking an analytic approach, the authors construct and study an IRR function satisfying appealing mathematical and economic properties. Furthermore, they show an important relation between the last two approaches discussed above. On the applied side, a ranking criterion developed to address concerns frequently arising in business practices is presented in Wong (2000).

Other authors (e.g. Cantor and Lippman (1983, 1995)) consider a multi-period investment environment. Here, the investor is maximizing his terminal wealth when the assumption of perfect capital markets is abandoned and a borrowing constraint is imposed. Cantor and Lippman show that in such an environment NPV and IRR attain a new interpretation, and can be utilized to arrive at an optimal investment selection.

3. Necessary and Sufficient Conditions on Moments

Consider $g(t)$ to be a signed measure, and decompose it into positive and non-positive parts.[6] With $g^u(t) = \max[g(t), 0]$ and $g^l(t) = -\min[g(t),0]$, present value (1) may be written as $N(r) = \int_0^\infty [g^u(t) - g^l(t)]e^{-rt}dt$, and we seek to establish when

$$\text{sign}\,[N'(r)] = -\text{sign}[\int_0^\infty t\,[g^u(t) - g^l(t)]e^{-rt}dt], \tag{2}$$

is invariant to the choice of $r \in \Re_{++}$. Here the prime indicates a differentiation. Assuming that $N'(r) \leq 0$ is required, then we seek regularity conditions on $g(t)$ such that

$$\int_0^\infty t\, g^u(t)\, e^{-rt}\, dt \geq \int_0^\infty t\, g^l(t)\, e^{-rt}\, dt \ . \tag{3}$$

Next, we expand the exponential function to obtain

$$\int_0^\infty t\, g^u(t) \left[\sum_{i=0}^\infty \frac{(-r)^i}{i!} t^i \right] dt \geq \int_0^\infty t\, g^l(t) \left[\sum_{i=0}^\infty \frac{(-r)^i}{i!} t^i \right] dt\,. \tag{4}$$

[6] See Royden (1988, p. 273) on signed measures. Cash flows are defined up to sets of measure zero.

Throughout the paper we maintain:

Assumption 3.1: *Functions* t^j *and* $t\,e^{-rt}$ *are integrable with respect to absolute measure* $\int_0^t |g(s)|ds$ *on* $t \in \Re_+$.[7]

This allows us to interchange operations and obtain the equivalent requirement

$$\sum_{i=0}^{\infty} \frac{(-r)^i}{i!} \int_0^{\infty} t^{i+1} g^u(t)dt \geq \sum_{i=0}^{\infty} \frac{(-r)^i}{i!} \int_0^{\infty} t^{i+1} g^l(t)dt\,. \tag{5}$$

Define $\mu_j^u = \int_0^{\infty} t^j g^u(t)dt$ and $\mu_j^l = \int_0^{\infty} t^j g^l(t)dt$ as the *j*-th upper and lower moments, respectively, of $g(t)$ whenever such moments are well defined. Then we may write (5) as

$\sum_{i=0}^{\infty} \frac{(-r)^i \mu_{i+1}^u}{i!} \geq \sum_{i=0}^{\infty} \frac{(-r)^i \mu_{i+1}^l}{i!}$, or

$$\mu_1^u - \frac{\mu_2^u}{1!} r + \frac{\mu_3^u}{2!} r^2 - \frac{\mu_4^u}{3!} r^3 + \ldots \geq \mu_1^l - \frac{\mu_2^l}{1!} r + \frac{\mu_3^l}{2!} r^2 - \frac{\mu_4^l}{3!} r^3 + \ldots. \tag{6}$$

And so

Proposition 3.1. $N'(r) \leq 0$ *iff* $\sum_{i=0}^{\infty} \frac{(-r)^i \mu_{i+1}^u}{i!} \geq \sum_{i=0}^{\infty} \frac{(-r)^i \mu_{i+1}^l}{i!}$ *for all* $r \in \Re_{++}$.

To illustrate, suppose that the cash flow restriction $\int_0^{\infty} tg^u(t)dt = \int_0^{\infty} tg^l(t)dt$ pertains so that we can invoke results in probability theory.[8] Then inequality (5) holds if and only if the distribution

$$G^l(t) = \int_0^t sg^l(s)ds \Big/ \int_0^{\infty} sg^l(s)ds$$

dominates

[7] See Royden (1988, p. 266) on integrable functions.

[8] That is, time weighted integration of cash inflows to infinity equals the time weighted integration of cash outflows to infinity.

$$G^u(t)=\int_0^t sg^u(s)ds\Big/\int_0^\infty sg^u(s)ds$$

in the Laplace transform order.[9] Denote this dominance order by $G^l(t)\geq^L G^u(t)$. For $G^l(t)\geq^L G^u(t)$ to hold, it suffices that $G^l(t)$ dominate $G^u(t)$ in the second-degree stochastic dominance sense or in the first-degree stochastic dominance sense. So if $G^l(t)$ maps to $G^u(t)$ through a Rothschild and Stiglitz (1970) mean-preserving spread operation, then $N'(r)\leq 0$. Alternatively, $G^u(t)\geq G^l(t)$ suffices for $N'(r)\leq 0$.[10]

4. Sufficient Derivative Conditions

While Proposition 3.1 provides an exact characterization of when the net present value function is monotone, the result may not be readily implementable. One problem is that the requirement of knowledge on all moments of inflows and outflows may be too onerous. Another problem is that analysts may find it more natural to characterize cash flows by level and derivative attributes on the flow function than by moments. In this section we find sufficient conditions on how the levels and derivatives of a cash flow relate such that monotonicity of net present value in the discount rate is preserved. Product integrands where a term in the product is an exponential function, yield succinctly to integration by parts. We use this fact, together with some regularity assumptions, in our next approach:

Assumption 4.1: *$g(t)$ is k_1-times continuously differentiable on $t\in\Re_+$.*

Assumption 4.2: $\lim_{t\to\infty} e^{-rt}d^{k_2}[t^{k_1}\,\mathrm{g(t)}]/dt^{k_2}=0, \forall\ r\in\Re_{++}, \forall\ k_2\in\{0,1,\ldots,k_1\}$.

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[9] Please see p. 95 of Shaked and Shanthikumar (1994). With $E[\cdot]$ the expectation operator, random variable $x_1\geq 0$ dominates $x_2\geq 0$ in the Laplace transform order if $E[e^{-rx_1}]\leq E[e^{-rx_2}]$ for all $r>0$.

[10] By pairing off sets of corresponding upper and lower moments in the pair of infinite summations in (5), a variety of sufficient conditions that ensure monotonicity can be derived. There are many ways of expressing inequality (5) as an inequality on a sum of finite-order polynomials. For each, some analysis can give a set of sufficient conditions under which (5) adheres.

Assumption 4.2 is a transversality condition that allows the avoidance of boundary value problems.[11] It is always satisfied when cash flows vanish at infinity. The appropriate choices of k_1 will become apparent in due course. But first, a useful lemma:

Lemma 4.1: *If* $\exists k_2 \in \{0, 1, \ldots, k_1\}$ *such that* $d^{k_2}[t^{k_1} g(t)]/d t^{k_2} \leq (\geq) 0 \quad \forall t \in \Re_+$, *then* $\int_0^\infty t^{k_1} g(t) e^{-rt}\, dt \leq (\geq) 0$. *And strict inequality conditions imply strict inequality inferences.*

Proof. Repeated integration by parts, together with Assumption 3.2, yields

$$\int_0^\infty t^{k_1} g(t) e^{-rt} dt = \frac{1}{r^{k_2}} \int_0^\infty \frac{d^{k_2}[t^{k_1} g(t)]}{dt^{k_2}} e^{-rt} dt \quad \forall\, k_2 \in \{0, 1, \ldots, k_2\}.$$

And we see that if any one of the $d^{k_2}[t^{k_1} g(t)]/dt^{k_2}$ has uniform sign on $t \in \Re_+$, then expression $\int_0^\infty t^{k_1} g(t) e^{-rt} dt$ must also have that sign. □

One can view, as Grubbström (1991) among others did, the valuation of a project as a Laplace transform of net cash flow $g(t)$. The Lemma may be interpreted as a Laplace transform result. An immediate deduction from the Lemma is:

Corollary 4.1. *Let* $k_1 = 1$ *in Assumptions* 4.1 *and* 4.2. *Then* $N'(r) \leq 0$ *if* $tg'(t) + g(t) \geq 0$.

This inference can be interpreted as a requirement for the net cash flows to have the sum of marginal and average net cash flows positive at all times. Alternatively the condition may be written as $tg'(t)/g(t) \geq -1$ for $g(t) > 0$ and $tg'(t)/g(t) \leq -1$ for $g(t) < 0$. In words, when the net cash flow is positive (negative), the cash flow elasticity with respect to time has to be greater (less) than minus one for an increase in the interest rate to decrease NPV, i.e., when the net cash flow is positive it cannot fall at too fast a rate and when the net cash flow is negative it must be rising at a rate that is not too slow. Further, if $g(t) \leq 0$ then $g'(t) \geq 0$ so

[11] A comprehensive study of transversality conditions is provided in Chapter 7 of Léonard and Long (1992).

that $g(t)$ changes sign no more than once and such a change cannot be from a positive value to a negative value.

One can easily adapt this result to deduce the condition when an increase in the rate of return will always preserve the ordering of the projects= NPV. Define $g(t) = h(t) - m(t)$ as the difference between the net cash flows of the two projects. Then $N(r) = \int_0^\infty h(t)e^{rt}dt$ - $- \int_0^\infty m(t)e^{rt}dt$. Let there exist some $\bar{r} \in \Re_{++}$ such that $N(\bar{r}) \leq 0$. Then a condition under which this order can be preserved for any higher discount rate is given by

Corollary 3.1. *For cash flows* $h(t)$ *and* $m(t)$, *let* $k_1 = 1$ *in Assumptions* 3.1 *and* 3.2. *Let* $d\{th(t)\}/dt \geq d\{tm(t)\}/dt \quad \forall t \in \Re_+$, *and let there exist an* $\bar{r} \in \Re_{++}$ *such that* $N(\bar{r}) \leq 0$. *Then* $N(r) \leq 0 \quad \forall\, r \in [\bar{r}, \infty)$.

We can rewrite this in the form $h(t)[1 + t\,h'(t)/h(t)] \geq m(t)[1 + t\,m'(t)/m(t)]$. In words, suppose that (a) the product of the cash flow level and its elasticity, augmented by one unit, for project $h(t)$ exceeds the corresponding expression for project $m(t)$ and (b) $m(t)$ has a larger NPV that $h(t)$ when $r = \bar{r}$. Then $m(t)$ continues to dominate on $[\bar{r}, \infty)$.

We now turn to the last set of sufficient conditions obtained by ruling out the best candidate to violate the monotonicity of NPV. Essentially we apply Lemma 4.1 to provide a distinct set of sufficient conditions on $g(t)$ that will guarantee $N'(r) \leq 0 \;\forall r \in \Re_{++}$.

Proposition 4.1: *If* (1a) $\mathrm{Lim}_{t\to\infty} e^{-rt}\, d^{k_a}[t^2 g'(t)]/dt^{k_a} = 0 \;\forall\, r \in \Re_{++},\; \forall\, k_a \in \{0,1,2\}$ while $\exists\, k_a \in \{0,1,2\}$ *such that* $d^{k_a}[t^2 g'(t)]/dt^{k_a} \leq 0 \,\forall\, t \in \Re_+$, *and* (1b) $\exists\, k_b \in \{0,1,2,3\}$ *such that* $d^{k_b}[t^3 g(t)]/dt^{k_b} > 0 \,\forall\, t \in \Re_+$, *then* $N'(r) \leq 0 \;\forall\, r \in \Re_{++}$.

Proof. Note, if $N'(r) \leq 0 \;\forall\, r \in \Re_{++}$ then $\sup_{r\in\Re_{++}} \int_0^\infty [-t\,g(t)]\, e^{-rt}dt \leq 0$. The first- and second-order conditions for this optimization problem are

$$\int_0^\infty t^2 g(t)\, e^{-rt}\, dt = 0, \qquad \int_0^\infty t^3 g(t)\, e^{-rt}\, dt > 0, \tag{7}$$

respectively. Condition (1b), applied to Lemma 4.1, ensures concavity. An integration by parts of the first order condition gives $\int_0^\infty [2\,t\,g(t) + t^2 g'(t)]e^{-rt}\,dt = 0$, or

$$-\int_0^\infty t\,g(t)\,e^{-rt}\,dt = N'(r) = \frac{1}{2}\int_0^\infty t^2 g(t)\,e^{-rt}\;dt \tag{8}$$

and so the largest value of $N'(r)$ over $\forall r \in \Re_{++}$ has the sign of $\int_0^\infty t^2 g'(t)\,e^{-rt}\,dt$. From the condition in (1a) and application of Lemma 4.1, the latter integral is nonpositive. □

For $k_a = k_b = 0$, conditions (1a) and (1b) are not very interesting. With $k_a = k_b = 1$, the conditions are $2\,g'(t) + t\,g''(t) \le 0$ and $3g(t) + t\,g'(t) > 0$, or $-3g(t)/t < g'(t) \le tg''(t)/2$. To see that Corollary 4.1 and Proposition 4.1 are distinct, consider $g(t) = t^2$. For this, the conditions for Corollary 4.1 are met whereas the conditions for Proposition 4.1 are not. However, when $g(t) = (t+1)^{-2}$ then the conditions for Proposition 4.1 are met whereas those for Corollary 4.1 are not.[12]

5. IRR Comparison of Projects

To this juncture we have considered when a given project behaves well with regard to changes in the discount rate. A natural analog to this trait when comparing a set of projects is when the projects are sufficiently structured that each has a unique IRR and the set of IRRs can be ranked in a known way. Let H be the set of all cash flows such that $v(t) \in H$ implies $\exists\ \hat{t} \in \Re_+ \ni v(t) \le 0\ \ \forall\ t \in [0,\hat{t}]$ and $v(t) > 0\ \forall t \in (\hat{t},\infty)$. That is, there is a single crossing and it is from cash outflows to cash inflows. This applies automatically when $tv'(t) + v(t) \ge 0$, a condition that arose in Corollary 3.1.

[12] Proposition 4.1 requires global concavity of $N'(r)$. This is a strong restriction, which is unrelated to the conditions required by Corollary 4.1. On the other hand, both sets of conditions are restrictive so that they complement each other.

Choose $g(t) \in H$ and $h(t) \in H$, and suppose that there exists a scalar λ such that $g(t) \leq \lambda h(t)\ \forall t \in \Re_+$. It is readily shown that there is a unique IRR, call it r_v, for any $v(t) \in H$.[13] A little work then maps condition $g(t) \leq \lambda\, h(t) \forall\ t \in \Re_+$ into project dominance in the IRR sense.

Proposition 5.1: *If* 1a) $\exists\ \lambda \in \Re$ *such that* $g(t) \leq \lambda\, h(t) \forall\ t \in \Re_+$, *and* 1b) $g(t) \in H$, $h(t) \in H$, *then* $r_g \leq r_h$.

Proof. We have[14]

$$\int_0^\infty h(t)\, e^{-r_h t} dt = \int_0^\infty \lambda\, h(t)\, e^{-r_h t} dt = 0 \geq \int_0^\infty g(t)\, e^{-r_h t} dt. \tag{9}$$

Let $r_g + \delta = r_h$ where we seek to ascertain the sign of δ. Upon applying an integration by parts,

$$\int_0^\infty g(t)\, e^{-r_h t}\, dt = \int_0^\infty g(t)\, e^{-(r_g+\delta)t}\, dt = \int_0^\infty e^{-\delta t} g(t)\, e^{-r_g t}\, dt = \delta \int_0^\infty e^{-\delta t} \int_0^t g(s)\, e^{-r_g s}\, ds dt.$$

Because $g(t) \in H$, it follows that $\int_0^t g(s) e^{-r_g s}\, ds \leq 0\, \forall\, t \in \Re_+$. From (4.1), it must be that $\delta \geq 0$. □

Notice, we did not impose a sign on λ. In fact, it must be positive under the conditions in the proposition. To see this, note that if $\lambda < 0$ then condition $g(t) \leq \lambda\, h(t)$ is violated on $t \geq \max[t_g, t_h]$.

Now consider a set of projects, $\{g_1(t), g_2(t), \ldots, g_n(t)\} \in H$. If we happened to find a set of (positive) numbers, $\{\lambda_{1,2}, \lambda_{2,3}, \ldots, \lambda_{n-1,n}\}$, such that $g_i(t) \leq \lambda_{i,i+1}\, g_{i+1}(t) \forall\ i \in \{1, 2, \ldots, n-1\}$ then it is assured that $r_{g_1} \leq r_{g_2} \leq \ldots \leq r_{g_n}$. The set of projects are well

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[13] Suppose not. Then there exists a $\tau \neq 0$ such that $\int_0^\infty v(t)\, e^{-(r_v+\tau)t}\, dt \equiv \int_0^\infty e^{-\tau t}\, v(t)\, e^{-r_v t}\, dt = 0$. If $\tau > 0$, then $e^{-\tau t}$ is a positive decreasing function of t. The property $v(t) \in H$ together with an integration by parts yields $\int_0^\infty e^{-\tau t}\, v(t)\, e^{-r_v t}\, dt < 0$. If $\tau < 0$, then $\int_0^\infty e^{-\tau t}\, v(t)\, e^{-r_v t}\, dt > 0$.

[14] This proposition, whereby $g(t)$ substitutes for $\lambda\, h(t)$ in an optimization problem, is an example of the diffidence method as applied in Gollier (1995). Gollier provides a related graphical depiction.

behaved in the sense that their unique IRRs can be ordered upon inspection of the cash flows. Suppose, for the sake of illustration, that $g(t) \leq \lambda h(t)$ with $\lambda = 2$. Figure 1 depicts how the cash flows might then relate. Observe that $t_g \geq t_h$ must apply if the condition is to hold.

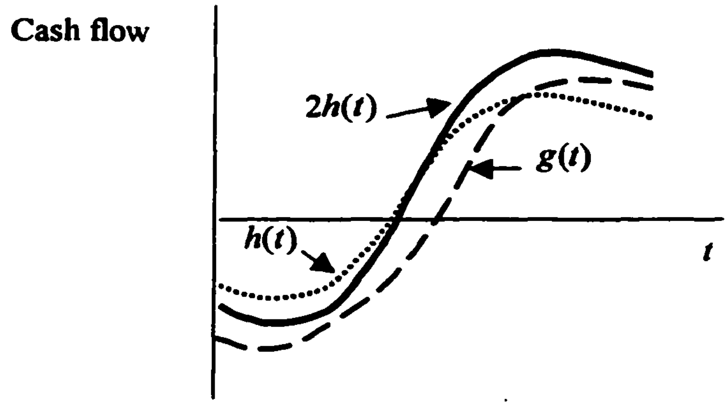

Figure 1. Cash flow dominance such that IRRs can be ranked.

6. Concluding remark

A large literature is emerging on adapting and applying mathematical order concepts to economics.[15] We have demonstrated that some of these approaches may be able to reconcile anomalies in approaches to the pervasive task of project valuation. Most of what we have done generalizes in at least one sense. The functions $e^{-rt}, r \in \Re_{++}$, comprise a complete set of extreme points for the convex cone of completely monotone functions.[16] A version of most of our findings carries through if e^{-rt} is replaced by completely monotone function $v(r\,t)$. But other generalizations, such as accommodating a non-constant yield curve, are warranted.

[15] See, e.g., Milgrom and Shannon (1994) or Athey (1998).

[16] $v(x)$ is completely monotone if $(-1)^n \, d^n v(x) / dx^n \geq 0 \;\; \forall x > 0, \;\; \forall n \in N_0$. See Athey (1998) for applications of the convex cone method, and Shaked and Shanthikumar (1994, pp. 95–96) for verification that $e^{-rt}, r \in \Re_{++}$, do comprise a complete set of extreme points for the set of completely monotone functions.

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CHAPTER 3. LOCATION, LAND QUALITY, AND RENTAL VOLATILITY

A paper to be submitted to a journal in the field

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Abstract

It appears to be widely believed that returns on low quality land are more variable than on high quality land. Using Ricardian rent as the measure of returns, and using sensitivity to output price as the measure of volatility, we investigate this null hypothesis for two different measures of quality: proximity to market and output productivity. In each case, we identify precise conditions on the production technology such that rental volatility varies in a monotone manner with land quality. Using panel data with temporal and spatial dimensions, we investigate the relationship between rental volatility and land quality for Iowa cash rents during 1994-2001. Our findings provide little empirical support for the null hypothesis of an inverse relationship between quality and rental volatility with respect to commodity prices.

Introduction

As an input in production, land has value to the extent that it contributes to generating economic surplus. Thus, however measured, land value should bear ordinal and monotone relationships with both the rent it commands in the marketplace and the land's capacity to produce. But the relationship between land value and the variability of returns as product prices change is not immediately clear. The conventional approach to assessing land values, the Present-Value Constant Discount Rate (PV-CDR) model, does not appear to explain land prices very well. Falk (1991), Clark, Fulton and Scott (1993), Lence and Miller (1999), and others present evidence to this effect. But Lence and Miller cannot rule out that model when transactions costs are recognized and the planned holding time is short. Chavas and Thomas (1999) concur that transaction costs are important, and also find econometric evidence suggesting the importance of risk aversion as a determinant of land prices.

The focus of our attention is not, however, on the asset market but rather on the short-term rental market where it is more likely that optimal pricing behavior occurs, where risk issues are of less consequence, and where the role of transactions costs is not as prominent. We seek to understand the relationship between land quality and the variability of rental returns as product prices change. The problem merits consideration because if a variant of the present value approach does underpin land pricing behavior then the way in which land quality affects rental volatility will have a bearing on the relationship between land quality and land price volatility. The problem is also important because commodity prices may remain depressed for sustained periods. And so the recipients of land rents most affected by depressed prices may face severe liquidity problems. Because there tends to be a strong positive spatial correlation between land quality attributes, the impact of depressed product prices may be systemic at the community and regional levels. This should be of concern to bankers and those responsible for forming rural policy, especially if asset and risk management markets are not well developed.[1]

The effect of land quality on rent sensitivity to price fluctuations may also be important in environmental policy. The United States, among other countries, has periodically intervened in land rental markets in order to manage commodity supplies and to influence environmental conditions. The approach has been to offer long-term fixed rent contracts. The quality profile of land entering the program will depend upon the variability of rental returns on the land. One might expect that, due to risk aversion, if there is a strong positive correlation between rent variability and land quality then, other things fixed, the better quality land will be signed up.

But little in the way of formal analysis has been conducted on the topic. The preponderance of opinion is that returns on lower quality land are more variable. Benirschka and Binkley (1994) identify anecdotal evidence to support this hypothesis. In their own empirical analysis they work with county-level land price data in Ohio, Indiana, Illinois, Missouri, and Iowa over the time intervals 1969-82 and 1982-87. Using loan rate data as a proxy for distance to market, and controlling for non-location determinants of quality, they

[1] While the U.S. has, in general, well-developed asset markets, this is not true for the class of rural land assets.

find support for the hypothesis that land prices are more volatile in remote locations. But, while they suggest that the relation is an outcome of economic theory, they do not provide a detailed theoretical foundation for their findings.

Working at the rental level, we identify conditions on the production environment such that land rental value sensitivity to the output price environment is ordered in a monotone manner by land quality. In part one of this paper, we use two separate measures of quality: a geographical (i.e., basis) concept and a productivity index concept.[2] In both cases we find that there is no theoretical reason why rental volatility should be inversely correlated with land quality. The intent of the second part of this paper is to conduct an empirical investigation of the relationship between rental sensitivity to output price and land quality for Iowa counties from 1994 to 2001. We describe the data and explain how our regression analysis accounts for spatial and temporal autocorrelations among the disturbances. We conclude with some discussion of our estimation results.

Basis and Rent Volatility

A farm operator is assumed to cash rent cropland on an annual basis. The rental price is set in a competitive market at time 0, the beginning of the year, and harvest occurs at time 1, i.e., at year end. In seeking to establish the Ricardian rent, the operator establishes land profitability with reference to a locked in harvest-time futures price, F. The local basis at maturity is B, defined as the difference between local and futures prices at harvest, and there is assumed to be no basis risk. Therefore, the operator can lock into a local price, $F + B$, through forward or futures contract positions. Ignoring yield risk, the operator may ascertain that the maximized economic profit, gross of cash rent, is $R(F + B)$. In a competitive land market, this is the rental price that will pertain. From standard economic theory we know that this function is increasing and convex. We also assume that it is strictly positive over the plausible domain of local prices. Our concern is with the volatility of this rental price. Denote the

[2] Another approach to measuring land quality, not pursued in this paper, would be to construct a cost efficiency (cost penalty) index.

fractional sensitivity, or volatility, of the rent function by $V(F+B) = R'(F+B)/R(F+B)$ $= d\ln[R(F+B)]/dF$ where the number of primes indicates the order of differentiation.

Now, all other things fixed, let us move closer to the delivery point so that the basis increases toward zero. We seek to understand how $V(F+B)$ change with B. It is clear that the answer lies in the sign of

(1) $$L(B) = \frac{dV(F+B)}{dB} = \frac{d^2\ln[R(F+B)]}{dB^2}$$

If $L(B) \leq 0$, then $R(F+B)$ is said to be log-concave over the domain. In this case disadvantages in location exacerbate land rental volatility. If $L(B) \geq 0$ over the domain then $R(F+B)$ is said to be log-convex, and land rental volatility is ameliorated by remoteness from market.[3]

RESULT 1. *An increase in basis B reduces (increases) Ricardian rent volatility if the Ricardian rent function is log-concave (log-convex).*

Clearly, $L(B) \leq (\geq) 0$ according as

(2) $$R(F+B)R''(F+B) \leq (\geq) [R'(F+B)]^2$$

Note that concavity of $R(F+B)$ ensures log-concavity, but the converse is not true. We know that $R''(F+B) \geq 0$, so the sign of $L(B)$ cannot be immediately ascertained. Through a sequence of examples, we will show that it can plausibly be of either sign.

EXAMPLE 1: Suppose, as Benirschka and Binkley (1994) do in their graphical example, that the rental function is quadratic so that the supply function is linear. With $B = 0$, for convenience, write $R(F) = a_0 + a_1F + a_2F^2, a_0 < 0, a_1 \geq 0, a_2 > 0$. Then $L = [2a_0a_2 - a_2^2F^2 - (a_1 + a_2F)^2]\ /[R(F)]^2 < 0$.

[3] It is interesting to note that the log-concavity property has been widely studied in the statistics literature. See Shaked and Shanthikumar (1994) for statistical applications, while An (1998) and Chen (1997) provide economic applications.

EXAMPLE 2: Suppose that the rental function is the power function, $R(F) = a_0 F^{\varepsilon}$, $a_0 > 0, \varepsilon > 1$. Then $L = -a_0^2 \varepsilon F^{2\varepsilon-2} / [a_0^2 F^{2\varepsilon}] < 0$.

EXAMPLE 3: Suppose that the rental function has expo-power function form, otherwise known as the Weibull functional form,[4] $R(F) = a_0 + a_1 \exp[a_2 F^{\alpha}], a_0 < 0, a_1 > 0, a_2 > 0, \alpha \geq 1$. Here the coefficients have been restricted to ensure convexity and also that $R(0) < 0$. Then L has the sign of $a_0(\alpha - 1) + a_0 \alpha\, a_2\, F^{\alpha} + (\alpha - 1) a_1 \exp[a_2 F^{\alpha}]$. It is immediate that there exists an interval $(a_0^{*}, 0]$ of strictly positive length such that $a_0 \in (a_0^{*}, 0]$ implies that $L > 0$.

This last example shows that theoretical support for the claim $L \leq 0$ must presuppose more structure on the profit function than just convexity.

Yield Productivity Index and Rent Volatility

Suppose that the quality of cash rented land could be captured by an exogenous parameter that multiplies a common production function. For a reference acre of unit quality, let input vector q permit production of up to $G(q)$. For an acre of quality $u > 0$, production is $u\,G(q)$. Suppressing factor prices, we can conclude that the Ricardian rent is $R(uF)$. For $u_2 > u_1$, an increase in land quality decreases (increases) rent volatility if $d \ln[R(u_2 F)] / dF \leq (\geq)\ d \ln[R(u_1 F)] / dF$ on the relevant domain of F.

RESULT 2. *An increase in productivity index u reduces (increases) Ricardian rent volatility if the Ricardian rent function satisfies* $d^2 \ln[R(uF)] / dF du \leq (\geq) 0$.

We have then that volatility increases for all $u > 0$ if

[4] See Saha (1993) for an application of this functional form as an utility function.

(3) $$R(z)R'(z)+\{R(z)R''(z)-[R'(z)]^2\}z \geq 0,\ z=uF.$$

This is clearly a weaker condition than the log-convexity condition (2), and so example 3 is a case where an increase in quality increases rent volatility. Or for example 2, the power profit function, condition (3) is always satisfied with equality. And for example 1, condition (3) reduces to $a_0a_1+4a_0a_2F+a_1a_2F^2 \geq 0$, a plausible requirement when F is sufficiently large.

The main objective of the last two sections was to demonstrate that, at least theoretically and in a world of optimizing agents, rental volatilities bear indeterminate relationships with land quality. And so evidence on these relationships reveals something about the nature of the underlying technology.[5] We proceed by integrating results 1 and 2 to derive some testable hypotheses that can be confronted with the data. Imagine that cropland parcels are ordered by both measures of land quality: the basis, B, and *multiplicative* yield productivity index, u. Then conditions (2) and (3) imply that the effects of these two quality measures on rental volatility are related. For example, if $L(B)\geq 0$ then condition (3) must always hold. In words, we should not expect to find that rental volatility responds positively to a more advantageous geographical location but negatively to a higher yield productivity. On the other hand, if an increase in u reduces Ricardian rent volatility $V(u(F+B))$ (i.e., condition (3) holds in the reverse direction) then we must have $L(B)\leq 0$. The theory predicts that we cannot observe a higher rental volatility for a less productive acre and a lower volatility for a similar acre that is located further from the market. However, both of these propositions hinge on the assumption that yield productivity is represented by a multiplicative index, which already presupposes a great deal of structure on the production function.[6]

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[5] To be more specific on this point, observe that both of our results concern the sign of $d^2\ln[R(F,\tau)]/dFd\tau$ where τ is one of $\{B,u\}$ and where additional structure might have been imposed on the rent function. When $d^2\ln[R(F,\tau)]/dFd\tau \geq 0$ on the relevant domain, then the rent function is said to be log-supermodular. If the sign is negative on the relevant domain then the rent function is log-submodular. The log-supermodularity property has arisen in economic analyses of uncertainty by Athey (1996) and others.

[6] Formally, such tests of the theory amount to testing whether the statement that $R(F+B,u)\equiv R(u(F+B))$ holds up empirically. Running ahead, the section where we discuss our estimation results provides circumstances when the assumption that a measure of yield productivity enters the Ricardian rent function multiplicatively is violated.

Now we turn to an empirical analysis of the correlation between rental volatility and farmland quality in Iowa counties over the period 1994 to 2001. The sections to follow describe the data on rental rates, expected output prices and land quality measures. It is conjectured that the disturbances are likely to be spatially and temporally autocorrelated because of the time-series cross-section data. We present an econometric technique to deal with the two-dimensional autocorrelation and use it to estimate the curvature of the Ricardian rent function based on the accumulated data set.

Data on Rental Rates and Land Quality

To provide some empirical evidence of how the sensitivity of rental rates to the output price relates to land quality, we studied the survey data *Cash Rental Rates for Iowa* collected during 1994-2001 (Edwards and Smith). The collected series appears to be unique because, to our knowledge, there is no other consistently collected series of cash rental estimates at a county level that spans more than 8 years and covers an entire state. This publication provides a reasonably accurate measure of typical cash rents for corn and soybeans at the county level. The cash rental rate in each county is, typically, calculated as an average of 12-18 responses from farmers, landowners, agricultural lenders, real estate brokers, and professional farm managers.

However, some care is warranted in clarifying how the cash rental rates reported by Edwards and Smith are measured. There are at least five approaches to setting cash rental rates in the Corn Belt states: percent of land value, crop share equivalent, share of gross income, tenant's residual, and yield potential (e.g., Eggers, Mayer, and Thomas (1998)-EMT). In addition, cash rental arrangements can be classified as fixed or flexible depending on whether the amount of the rent is adjusted for actual yields and/or output prices (Langemeier 1997). Also, payment provision may be for one single annual payment or for two installments (say a half is to be paid in March and the other half in the following Fall). In the surveys done by Edwards and Smith, respondents supplied their information based on their best judgment assuming that half the rent is paid before planting and the remainder following harvest. Therefore, the recorded cash rental rates are likely to be relatively free from any bias arising from heterogeneity in respondents' assumptions concerning the terms of the rental contract.

We seek to investigate how cash rents behave as a function of land quality characteristics. To do so, we use two readily available measures of land quality and location: (i) the corn suitability rating (CSR) index measuring the soil productivity, and (ii) the county loan rates used to calculate a proxy for the basis. These measures of land quality and location are briefly discussed below.

Corn Suitability Rating

CSRs provide a relative ranking of all soils based on their potential to be utilized for intensive row crop production (Iowa Agriculture, p. 9).[7] The CSR is an index that can be used to rate one soil's potential yield against another over a period of time. This index considers average weather conditions as well as frequency of use of the soil for row crop production. The most productive soils have an index of 100, and soils in Iowa usually range between 62 and 88. The construction of the CSR index is based on agronomic measures of soil quality rather than on actual yields. This makes the CSR index attractive for our study, as it does not embody any effects of profit maximizing behavior and immediately provides us with a yield productivity index. Other measures of soil quality, such as land capability classes, may serve the same purpose and can be used to explain the land values. However, these other measures do not appear to be as well-suited to measuring land quality in Iowa, the major corn-producing state. For example, a large share of Iowa farmland belongs to a single capability class.[8]

County Loan Rate

The basis at the county level, generally, reflects transportation costs and so is increasing (in absolute terms) in the economic distance to market. To measure the basis, we used the county

[7] The estimates of the CSR indexes in Iowa counties used in this study were taken from Edwards and Smith.
[8] Further details about the CSR index, land capability classes, and other soil characteristics can be found in Iowa Soil Properties and Interpretations Database Manual (Iowa Agriculture).

loan rates taken from yearly issues of the U.S. Department of Agriculture's *Schedule of County Loan Rates*. Non-recourse marketing assistance loans offer farmers an instrument to finance storage of their crops with an option to market them when output prices are higher. The harvested crop serves as collateral for a loan, which can always be repaid by delivering the crop to the Commodity Credit Corporation at loan maturity (U.S. Department of Agriculture's *Fact Sheet: Feed Grains*). The base *county* loan rates are derived from the national loan rates and twelve-month average posted county prices. National average (feed grain) loan rates are set annually based on historical prices, the stocks-to-use ratios, as well as certain statutory guidelines. For example, the corn and soybeans national loan rates are set at 85 percent of the simple average of prices received by producers during the marketing years for the five immediately preceding crops, excluding the highest and lowest prices.[9]

Based on terminal market prices, the posted county price is formulated to reflect actual market conditions in the county. Importantly, price adjustments are made by county and reflect market and transportation factors. So calculation of the county loan rates takes into account economic distance to the terminal markets for each individual county. Therefore, the following formula provides us with a good measure of the basis for corn (or soybeans) crop at the county level:

$$B_{i,t} = \text{County Loan Rate}_{i,t} - \max_i \left[\text{County Loan Rate}_{i,t}\right], \tag{4}$$

where i = county, t = year, and the resultant measure of the basis is measured in cents per bushel. A higher value of the basis corresponds to a more favorable location with respect to the terminal market (i.e., lower transportation costs).[10]

Econometric Considerations

Cash Rental Rates

Traditionally, empirical analysis of time-series data begins with testing for the presence of unit

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[9] Some upper and lower limits, as well as Secretarial discretion, apply (see USDA's *Fact Sheet: Feed Grains.*)

[10] As was brought to our attention by William Edwards (Iowa State University), besides distance to major markets, local demand for livestock feed and industrial uses such as ethanol production are likely to affect basis as well.

roots. However, the time series of cash rental rates used in this study is relatively short (only 8 years), and so any test for random walk type behavior is likely to be inconclusive. At the same time, the vast literature on land prices does not seem to have reached a unanimous opinion on the adequate modeling of rental time series. For example, Lence and Miller (1999), while investigating the role of transaction costs in the PV-CDR model, point out that the time series of the cash rents paid per acre of Iowa farm real estate during the period 1900 to 1994 appears to contain a unit root and therefore should be modeled in first-differences.[11] However, statistical artifacts aside, on purely economic grounds it is hard to imagine that the cash rent wanders "too far" away from the base level, particularly, in the short-run. What we mean by the base level of the cash rent is clarified below.

Unlike some macroeconomic variables or financial asset prices that are based on beliefs about the future earnings, the cash rent is simply the price of one of the inputs used in the farm production process. The profitability of farming is revealed quite frequently (say, annually at harvest). Therefore, unless output prices or the production environment are perceived to be highly volatile at the time the cash lease is signed and the rent is set, we expect that, on average, the cash rent is determined by the forces of competitive supply and demand. If the cash rent is too high or too low relative to the return on land from farming, the landowner and operator have an opportunity to renegotiate their contract in the following year. Consequently, in a fairly stable competitive environment where farming earns zero economic profit, cash rents should be closely tied to the output prices and production technology. With this thinking in mind, we use the (logarithm of) cash rental rates in levels as the dependent variable in the regression analysis to follow.[12]

Explanatory Variables

It seems reasonable to presume that the main determinants of the cropland rental rates comprise the expected output prices, productivity (yields), transportation costs (basis),

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[11] Lence and Miller arrived at an AR(1) model of the first-differenced real cash rents (adjusted for property taxes and inflation).

[12] In any event, the estimation using the first-differenced series of cash rental rates produces mixed and inconclusive results.

production costs, and USDA programs (Edwards 2001). We accentuate that we strive to estimate the Ricardian rent function, $R(F, \tau)$, which emerges as a result of grower's profit-maximization. Consequently, only variables that are truly *exogenous* to grower's production decisions will be used as regressors.[13] Therefore, the set of explanatory variables used in the regression consists of the following: a measure of the expected future output price environment, transportation costs, and the CSR index (a productivity measure).[14] Even though farm and commodity policies undoubtedly affect growers' production decisions and returns from farming, no variables representing the effects of these policies were included in the regression equation.

A radical change in U.S. agricultural policies occurred at the very beginning of our data set. During the last six years of observations, farm support programs were administered under the Federal Agriculture Improvement and Reform (FAIR) Act of 1996. While eliminating most of the previous restrictions on acreage use, FAIR provided eligible landowners with annual direct payments (Agricultural Market Transition Act) and continued to give farmers access to marketing loans. Unfortunately, we cannot meaningfully account for an effect on rental rates induced by fixed payments because our data set contains only two years of the period covered by the previous program (the 1990 Farm Bill).[15] On the other hand, during 1994-2001 the *expected* output prices never fell below a price floor (typically available to qualified growers), effectively set by marketing loans and deficiency payments.[16]

To measure the expected future output price environment, we use the harvest-time

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[13] For example, the history of actual county average yields that has a very significant impact on the rental rate, is not used as a regressor because actual yields are directly influenced by grower's decisions. In contrast, the prices of seeds, chemicals, herbicide, insecticide, machinery, farm labor, insurance, and interest rates can be safely enlisted as explanatory variables.

[14] Farm input price data were left out of the regression analysis, mainly, because it is difficult to obtain consistent data. For instance, the estimates of some input prices are not available at the county level. On the other hand, farm labor wages do not vary considerably across the state, and may not vary sufficiently over the period under study. In addition, construction of an input price index without including some of the input prices is likely to introduce a bias in the estimation results.

[15] In fact, as will be explained, we lose the initial year of observations because we use the one-year lagged value of the rental rates as an explanatory variable.

[16] FAIR payments were supplemented by both "market loss adjustment" payments for corn and "oilseed payments" for soybeans during 1997-2001.

maturity futures price for corn. Accounting separately for corn and soybeans appears to lead to multicollinearity among the independent variables.[17] To avoid this problem, we assumed that the main crop, corn, provided the output price that matters. Futures prices were calculated as a monthly average of year long corn futures contracts traded on the Chicago Board of Trade with the expiration dates in December of the following year. So, for example, the proxy for the expected output price in 1995 was based on the corn futures contracts maturing in December of 1996 as they were priced during August of 1995.[18]

Another econometric consideration is that the observations for each county should probably bear different weights because the popularity of cash rental arrangements varies across the state. According to one survey, 79% of the farm leases in Northern Iowa were cash leases in 1997 (EMT). Yet, only 36% of the farm leases in Southwest Iowa and 50% of the leases in South Central Iowa were cash leases. EMT rationalize this dispersion as being due to a greater variability in production in Southwest and South Central Iowa. Risk makes fixed cash leases relatively unattractive to farmers compared to other leasing arrangements.[19] Unfortunately, such data (say the number of acres cash rented in each county) do not appear to have been consistently collected during the period under study. So every county's cash rental rate has equal weight in our model.

Regression Equation

Note that the changes in both land quality measures, CSR and basis, are not time-sensitive and occur mainly across space (counties) while the change in the commodity prices takes place across time. On the other hand, rental rates vary along both temporal and spatial dimensions. Hence, to explain the variability in the cash rents, one needs to use panel data if all of the

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[17] During the period 1994-2001 the coefficient of correlation between the futures prices of corn and soybeans is equal to 0.82. To calculate the futures prices of soybeans, we used futures contracts maturing in November of the following year.

[18] While leases must be renegotiated in August, some people agree to postpone setting the rent for the coming year until a later date. Replacing August futures with an average of the harvest contract futures price from July through January produces similar estimation results.

[19] Sotomayor, Ellinger, and Barry (2000) identify income variability, soil quality, smaller tracts of leased acreage, shorter relationships with landlords, farmer's net worth and debt-to-asset ratios as factors associated with cash leases.

available information is to be utilized. The constructed data set contains observations for 94 counties during the time period from 1994 to 2001.[20]

We hypothesize that growers may not differentiate between the two sources of the expected farm-gate price: commodity futures price and the local basis, and use their sum, $F_t + B_i$, in their calculations.[21] The regression equation approximating a second-order Taylor series expansion of $R(F+B,CSR)$ is then given by:

$$\begin{aligned} \ln R_{i,t} &= \mu_0 + \mu_1 \ln R_{i,t-1} + \mu_2 (F_t + B_i) + \mu_3 CSR_i \\ &+ \mu_4 (F_t + B_i)\cdot CSR_i + \mu_5 CSR_i^2 + \mu_6 (F_t + B_i)^2 + \varepsilon_{i,t} \end{aligned}, \tag{5}$$

where $R_{i,t}$ is the cash rent that was paid in county i during year t, F_t is the expected output price given by the monthly average of corn futures prices (see page 12) in year t, CSR_i is the county i's corn suitability rating index discussed in the text[22], and B_i is the corn basis in county i (see Eqn (4)).[23] The lagged dependent variable is included to explicitly account for the (relative) infrequency of renegotiation of cash rental rates arrangements.[24] Given the panel nature of the data, we are interested in the signs of the regression coefficients on cross-product terms: $\mu_4 = \partial^2 \ln(R) / [\partial F\, \partial CSR]$, and $\mu_6 = 0.5 \cdot \partial^2 \ln(R) / [\partial F\, \partial B]$.[25]

Note that an alternative formulation of the regression equation that includes interaction terms, $F_t \cdot CSR_i$, and $F_t \cdot B_i$, would lead to the multicollinearity problem, arising mainly from the panel nature of the data. As was pointed out, the land quality characteristics

[20] Data on 94 out of 99 counties in Iowa were available for this study: data for some similar counties were combined. Additionally, the CSR indexes were not available for two counties.

[21] Here we neglect any risk issues that are likely to arise due to the timing of production and marketing decisions.

[22] In the actual regression, we divided the CSR index by 100. Note that variable CSR_i does not have the time subscript because the CSR index for a given county has remained nearly constant during the period 1994-2001.

[23] The corn and soybeans basis as measured by Eqn (4) are practically indistinguishable during the period from 1994 to 2001. Also, this measure of the basis has almost no variation across years. The time subscript in $B_{i,t}$ is, therefore, dropped to ease the notation.

[24] Alternatively, the lagged cash rent may serve to account for pressures on rental prices coming from non-agricultural uses of the land.

[25] These are the "short-run" responses. The "long-run" measures of the sensitivity are given by $\mu_4 /(1-\mu_1)$ and $2\mu_6 /(1-\mu_1)$.

vary from county to county but not from year to year. On the other hand, the expected commodity prices (not adjusted for the local basis) change strictly across time. Therefore, including the interaction terms in the regression results in a nearly perfect collinearity between CSR_i and $F_t \cdot CSR_i$, and B_i and $F_t \cdot B_i$.[26] The final term in (5), $\varepsilon_{i,t}$, also presents estimation problems because spatial and temporal autocorrelations among the disturbances are likely to be present. Accommodating these autocorrelations will be our primary consideration when choosing an econometric technique to estimate the regression equation (5).

Temporal and Spatial Autocorrelation

There are several reasons to conjecture that the regression residuals in Eqn (5) are probably correlated in both temporal and spatial dimensions. Being a contractual arrangement, cash rental agreements are liable to exhibit lagged behavior over time.[27] On the other hand, the data may exhibit spatial autocorrelation due to sharing of the common sources of information available to the farmers in contiguous counties. This, for example, includes using neighboring cash rental rates to negotiate one's own and regional soil water deficits. In addition, temporal and spatial correlation can be expected due to factors that are omitted from the regression.

The estimation of the regression equation in the presence of both patterns of autocorrelation appears to be a non-trivial issue.[28] This is a somewhat novel feature of our analysis. Because the disturbances are assumed to exhibit autocorrelation across time and across space, we propose the following error structure:

(6) $$\varepsilon_{i,t} = \rho\varepsilon_{i,t-1} + u_{i,t},\ u_{i,t} = \lambda\sum_{j=1}^{n} w_{ij}u_{j,t} + v_{i,t},$$

where $v_{i,t} \sim i.i.d.\ N(0,\sigma^2)$, $i = 1,2,\ldots,n$, and $t = 1,2,\ldots,T$.

[26] This problem is likely to disappear when the number of time periods and the number of spatial units are roughly equal. Note that the cross-product term $CSR_i(F_t + B_i)$ in Eqn (5) is not highly correlated with the terms CSR_i and $F_t + B_i$ because the expected local output price, $F_t + B_i$, varies along both dimensions.

[27] This may happen due to renegotiation costs. For example, an operator prefers to know well in advance what lot of land he (she) will be farming, in order to be able to plan for production inputs such as machinery and storage facilities. Then the operator may agree not to break a leasing agreement that charges too high a price if the costs of relocating are sufficiently large.

[28] For a recent review and discussion of the techniques used to model spatial autocorrelation in economics, please see Dubin (1998).

Here ρ is interpreted as a temporal autocorrelation coefficient, λ is a spatial autocorrelation coefficient, and w_{ij} is an element of a weighting contiguity matrix W, which is positive if counties i and j are contiguous and zero otherwise (e.g., see Benirschka and Binkley (1994)). The rows of the weighting matrix are normalized so that the sum of the elements of each row is one. We rewrite Eqn (6) in matrix form:

(7) $$\varepsilon_t = \rho\varepsilon_{t-1} + u_t,\ u_t = \lambda W u_t + v_t,\ v_t \sim N(0, \sigma^2 I).$$

Here ε_t, u_t, and v_t are column vectors of the regression disturbances for n counties in year t. From the second equation in (7), we obtain:

(8) $$u_t = (I - \lambda W)^{-1} v_t.$$

Writing the spatial component of the disturbances, u_t, as in Eqn (8) will be suggestive of a transformation that can be applied to the regression equation to assure that it satisfies the classical Gauss-Markov assumptions.

The parameters of the regression equation along with the correlation coefficients can be estimated using the method of maximum likelihood (ML).[29] For convenience, we rewrite the regression equation (5) in a general form $y_{i,t} = x'_{i,t}\beta + \varepsilon_{i,t}$, or in vector form:

(9) $$y_t = x'_t\beta + \varepsilon_t.$$

Transforming Eqn (9) through partial differencing, we obtain:

(10) $$y^*_t = x^{*\prime}_t\beta + u_t,$$

where $y^*_1 = y_1\sqrt{1-\rho^2}, x^*_1 = x_1\sqrt{1-\rho^2}$ and $y^*_t = y_t - \rho\, y_{t-1},\ x^*_t = x_t - \rho\, x_{t-1},\ \forall t > 1$.

Now substituting for u_t from Eqn (8), we have:

(11) $$y^*_t = x^{*\prime}_t\beta + (I - \lambda W)^{-1} v_t.$$

Finally, multiplying both sides of Eqn (11) by $(I - \lambda W)$ yields:

(12) $$y^{**}_t = x^{**\prime}_t\beta + v_t,$$

[29] For example, a general textbook treatment of spatial autocorrelation can be found in Cliff and Ord (1981). The GAUSS econometric software package provides a convenient routine for maximizing a user-defined likelihood function.

where $y_t^{**} = (I - \lambda W)y_t^*$ and $x_t^{**} = (I - \lambda W)x_t^*$.

Applying the change of variable formula where necessary, we obtain the likelihood function (note that only random variable $y_{i,t}$ is directly observable):

(13) $$L = (2\pi)^{-\frac{nT}{2}}(\sigma^2)^{\frac{-nT}{2}}\left(\sqrt{1-\rho^2}\right)^{n}|I - \lambda W|^T e^{-\frac{1}{2\sigma^2}\sum_{t=1}^{T}(y_t^{**} - x_t^{**'}\beta)^2}$$

where $|I - \lambda W|$ is the absolute value of the determinant of the transformation matrix

Regression equation (9) is then estimated by maximizing the likelihood function (13) over the regression coefficients β, temporal autocorrelation parameter ρ, and spatial autocorrelation parameter λ.

Estimation Results

The ML estimation results for Eqn (5) are presented in Table 1. Both the spatial and the temporal autocorrelation among the regression errors are found to be statistically significant at the one percent level, based on a likelihood ratio test. Also, the effects of expected (farm-gate) output price and land quality, measured by the CSR index, on the rental rate have the intuitively expected signs and are statistically significant. We discuss these effects in turn.

The previous year's cash rental rate appears to be a very important and significant factor. This confirms the belief that farmland rental contracts adjust sluggishly. As anticipated, the effect of the farm-gate output price, $F_t + B_i$, on the cash rental rate, $\partial \ln(R)/\partial(F + B)$, is positive for nearly 85% of F_t, B_i, and CSR_i observations of $R_{i,t}$ and statistically significant. Also, land with higher soil productivity, on average, seems to fetch a higher rental rate. The first-order derivative $\partial \ln(R)/\partial CSR$ is significantly different from zero (based on a likelihood ratio test for joint significance) and positive for approximately 75% of all observations.

Finally, the relationships between the rental rate sensitivity to output price and land quality measures are given by the following estimates of the second-order derivatives: $\partial^2 \ln(R)/[\partial F \partial CSR] = \underset{(0.151)}{0.0272}$, and $\partial^2 \ln(R)/[\partial F \partial B] = 2 \cdot \underset{(4.839)}{0.2503}$, where the numbers in parentheses are t-statistics. Thus, we find that the effect of the CSR index on rental volatility is not statistically significant. However, the relationship between the distance to market and the sensitivity of rental rates to the output price is significant and does not conform to the proposition suggested by Benirschka and Binkley (1994). In contrast to the conclusion drawn from their analysis of spatial land price data, we find that lower transportation costs (i.e., a higher basis) do not seem to imply a decline in the sensitivity of the rental rates to the output price.

Table 1. Estimation of Second-order Taylor Series Expansion of the Logged Rent Function $\ln[R(F+B,CSR)]$

Parameter	Estimate	Variable Description
μ_0	2.1679* (4.104)	Intercept
μ_1	0.883092* (42.587)	Lagged log of cash rent ($/acre)
μ_2	-1.1732* (-4.112)	Corn Price +Basis ($/bushel)
μ_3	-0.7546 (-0.968)	CSR index (%)
μ_4	0.0272 (0.151)	CSR index times local price
μ_5	0.4746 (1.131)	CSR index squared
μ_6	0.2503* (4.839)	(Corn Price +Basis) squared
λ	0.4210* (8.367)	Spatial autocorrelation
ρ	-0.3514* (-8.687)	Temporal autocorrelation
R^2	0.864	

Note: * denotes significantly different from zero at the 5% (1%) level of statistical significance, numbers in parenthesis are t-statistics, 658 observations.

A somewhat interesting issue is the sign of the time autocorrelation coefficient. The value of ρ is fairly robust to the regression specification and error structure (whether the spatial autocorrelation parameter is restricted to zero). As pointed out before, the presence of time autocorrelation can be interpreted either as a consequence of omitting factors pertinent to the time-series model explaining the cash rents, or a lag occurring in the landlord-tenant negotiation behavior. In general, it can be shown that $Cov(y_{i,t-1}, \varepsilon_{i,t})$ inherits the sign of time autocorrelation parameter ρ (e.g., see Greene 1997, p. 587). This implies a negative correlation between the previous year's cash rental rate and the likely deviation from the stable relationship based on the relevant economic factors in the subsequent year.

Discussion

These empirical results do not provide support for the view prevailing in the literature that posits a *negative* relationship between the quality of land and the land price sensitivity to the price of output (Benirschka and Binkley (1994)). As discussed above, there is no theoretical reason to presume a certain sign on the relationship unless one is willing to impose more structure on the underlying production technology than is usually assumed. As a case in point, using data for Iowa counties gathered during the period from 1994 to 2001, we find that the response of rental volatility to an increase in the basis is very significant and *positive*. On other hand, the data testifies to the lack of any statistically significant correlation between cash rent sensitivity to output price and the CSR index.

Consider the implications of finding no significant yield productivity effect for the functional form of Ricardian rent $R(u(F+B))$. In our analysis, we use the CSR index and the basis calculated as the difference between county loan rates as proxies for the yield productivity index, u, and the local basis at harvest, B, respectively. And so, the empirical analysis asserts that (see Eqn (1) and (2)):

$$\frac{\partial^2 \ln(R)}{\partial F \partial B} = \frac{(R R'' - (R')^2) u^2}{R^2} > 0, \tag{14}$$

$$\frac{\partial^2 \ln(R)}{\partial F \partial u} = \frac{R R' + (R R'' - (R')^2) u(F+B)}{R^2} = 0. \tag{15}$$

We should not attempt to solve the differential equation in (15)[30] because we know that the CSR index cannot enter the Ricardian rent function in the manner that the theoretical productivity index, u, does (please see footnote 6). If Eqn (14) and (15) were to hold simultaneously then we must have $R'(.) < 0$, which can be tested empirically. This hypothesis is immediately rejected by the data. There is a robust (and intuitively obvious) positive relationship between the expected output prices and the cash rent found in the data. Hence, we conclude that specifying the productivity index as an exogenous parameter augmenting the output price by a multiplicative factor may not be appropriate since it has no empirical support. Of course, other ways of representing the yield productivity index are possible. Or, alternatively, the finding of no relationship between the CSR index and the rental rate sensitivity may be erroneous.

There are several reasons to cast some doubt on the validity of the empirical finding that there is no linear relationship between rental volatility and land quality as measured by the CSR index. First of all, it is possible that the county level data does not provide sufficient variability in the explanatory variables. For example, it may be conjectured that the *cash rented cropland* in Iowa is of good quality that does not vary greatly over the state. In contrast, the geographical locations of the counties are not immaterial with respect to the shipping expenses. The variability in the loan rates across counties in Iowa, measured as a percentage of the output price, can be fairly sizable.[31] A partial remedy for that problem would be to analyze the data at the county level but for several corn and soybean producing states over a longer period of time. Note that the elimination of the time dimension from the analysis does not lead to a more statistically significant relationship. Studying the change in the cash rents only in the spatial dimension, in the spirit of Benirschka and Binkley (1994), yields mixed and inconclusive results.[32]

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[30] For example, the functional form of the relationship between the rental rate and the farm gate output price implied by the lack of the basis effect on rental volatility is given by $R(x) = c_2 e^{c_1 x}$, where c_1 and c_2 are arbitrary constants.

[31] Say, for the largest difference in the loan rates (referred to throughout this paper as basis) between the counties this number is 0.19/2.5 x 100% =7.6% when the commodity futures price is 2.5($/bushel).

[32] The relationships are positive in some years and negative in others, and they are almost always statistically insignificant.

This regression analysis has been conducted on the premise that no substantial changes in the production technology and input prices took place during the period from 1994 to 2001. This assumption may be put in question. For example, the introduction of biotech crop varieties since 1996 has certainly impacted the costs of production and expanded the input choices available to growers.[33] And so a comprehensive set of input price data would probably explain a considerable portion of the residual variation in the rental rates. On the other hand, USDA price support programs had also undergone important changes within the time period under study. A better understanding of how farm policies are reflected in rental arrangements is also likely to yield a valuable insight.[34]

Concluding Remarks

An important lesson gleaned from this analysis consists of the following. If the intent of an economic inquiry is to ascertain the role of asset quality on rent or asset price sensitivities to the output price environment, then a maintained production technology needs to be posed with care. The proposed production technology must be flexible in the sense that it admits all plausible responses to the measure of quality. Otherwise the object of inquiry may be imposed by the technology.

Our empirical investigation of rental volatility as a function of two land quality measures: yield productivity and distance to market, was based on the Iowa farmland cash rent time series during the period from 1994 to 2001. We found that rental volatility tends to be higher for the counties that are closer to the terminal market, which does not agree with the opinion prevailing in the literature. However, the estimated response of rental volatility to soil productivity characteristics was not significantly different from zero. Apparently, the collected data contains enough "noise" to render it infeasible to measure the cross-derivative of the profit function, $R(F+B,u)$. Of course, accumulating a larger data set (either in spatial

[33] For example, Duffy and Smith (2000) report typical production cost savings of 2.12 ($/acre) from using biotech soybeans instead of a standard variety in the year 2000.
[34] For example, see Babcock and Carriquiry (2001) for a discussion of the changes in planting incentives caused by the 1996 FAIR act. Edwards (1998) provides an analysis of possible changes in the formation of rental rates that have occurred as a result of FAIR from a farm management perspective.

or temporal dimensions) is likely to help us learn more about the connections between the rental volatility and land quality. In addition, explicitly recognizing the effects of input prices, production technology innovations, and agricultural policies on the profits from farming may also be expected to foster more conclusive test results.

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CHAPTER 4. PLANTING DECISIONS AND UNCERTAIN CONSUMER ACCEPTANCE OF GENETICALLY MODIFIED VARIETIES[1]

A paper accepted by American Journal of Agricultural Economics

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Abstract

There exists much uncertainty about consumer attitudes towards genetically modified foods. If it happens that sufficient (insufficient) acres are planted under non-modified seed to meet post-harvest demand, then a price premium will not (will) emerge for the non-modified varieties. A non-linearity originates in the fact that a price premium may be supported. This non-linearity interacts with demand uncertainty to determine equilibrium plantings and the probability that post-harvest varietal prices differ. Also, as planting approaches signals will be broadcast about the nature of post-harvest demand. We show how the non-linearity affects the types of signals that growers will prefer to receive.

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Introduction

The years 1996 through 1999 saw rapid increases in acres sown to genetically modified (GM) corn, soybean, cotton, and canola seed varieties in the US. However, the trend was reversed in the 2000 crop year. Among the many possible reasons for this reversal, we will study the possibility that it was due to a dearth of information concerning the nature and extent of difficulties that products derived from these varieties might face in accessing domestic and international markets.

Consumers appear to be either indifferent between varieties or to prefer non-modified (NM) varieties over GM varieties. And so, as observed by Lence and Hayes, arbitrage activities will ensure that the price of NM varieties in the market place will not fall below that of GM varieties. If the price spread were to become strictly negative, then an arbitrage opportunity would exist and arbitrageurs would supply NM varieties to the GM market until the prices equalize. In that light, growers who plant a GM variety that may encounter consumer resistance when it enters the marketplace can be viewed as accepting a restriction on post-harvest marketing opportunities for the resulting commodity. In making the decision to plant, the grower considers a trade-off. There is the premium that might be attained from an NM variety if the post-harvest market supports a price differential, while there are also the cost and yield benefits that the GM technology may deliver. At the market level, prospects concerning the premium provide incentives for acreage adjustments until an equilibrium in these trade-offs is asserted.

The intent of this article is two-fold. First, we will explore the role of uncertainty as a determinant of post-harvest equilibrium. In particular, we will inquire into the circumstances under which reduced certainty about post-harvest demand might induce producers to curtail plantings of a variety. Also, we study how the form of randomness affects the probability that a price premium is supported in the post-harvest market.[1] Second, we investigate the related issue of how a more informative decision environment can affect the types of market equilibrium that emerge. This paper consists of four main sections, the first of which details the origin and character of the problem. Essentially, one-way arbitrage will generate a non-linearity if there is a strictly positive probability that the post-harvest market will support a premium on NM varieties. And this non-linearity interacts with randomness on the demand side. In the second section an analytical model is developed, and conditions are found under which increased demand-side uncertainty does indeed impede the rate of varietal adoption. Implications of the non-linearity for the types of information that growers will benefit from are then established. We conclude with a brief discussion on issues arising in our analysis.

Background

Trends and Motives

Since the roll-out of GM seeds in 1996, GM crop varieties have come to play an important role in agricultural markets.[2] As can be seen from Table 1, the shares of the US corn and soybean crops planted to GM varieties had risen uniformly year-on-year until the 2000 crop year.[3] Further, the rate of adoption had been accelerating in the case of corn and cotton crops. For corn the increase in the share of US acres sown to GM varieties was larger over 1998-99 (at about 17%) than over the preceding year (about 11%). For cotton the increase in share was largest over 1998-99, after which a majority of acres were under modified varieties. For soybeans the growth rate began to decline by 1998-99 when modified varieties attained a majority share in total plantings.

In 2000, for the first time the acreage planted to GM corn and soybeans in the US would appear to have decreased relative to the preceding year. While the planting of GM crops in 2000 exceeded earlier estimates, the share of GM corn in all corn acres was down by about 9% and the share of GM soybeans in all soybean acres also fell.

Viewed from the supply side, the many appealing traits of early GM crop varieties are obvious motives for adoption. Commonly cited on-farm benefits responsible for the fast adoption of biotechnology in agriculture include: 1) reduced pest management costs; 2) enhanced yields; 3) reduced labor requirements; and 4) greater planting flexibility. For example, estimated production costs for GM soybeans in Iowa during the 2000 crop year were lower than for NM soybeans even though GM seed cost 40% more (Duffy and Smith, 2000a).[4] The primary reason for reversion in adoption during 2000 was unlikely to have been on the production side, but rather due to growing uncertainty about product demand.

Disquiet on the Demand-Side

All GM varieties that are permitted access to human food markets in the US must be certified by the Food and Drug Administration as being practically indistinguishable from existing NM varieties and so not hazardous to human health. Still, many consumers, especially in the European Union (EU) and Japan, have strong concerns about consuming these varieties. As a consequence, both the US domestic and international marketing systems have moved toward the segregation of biotech and non-biotech varieties. In 1999, demand for specifically non-biotech corn amounted to only 1% of US production (Lin, Chambers, and Harwood - LCH), and was due largely to demand in EU markets where GM labeling was required, demand from some Japanese brewers, demand for seed, and demand from some US food manufactures that elected to offer exclusively products not derived from biotech raw materials. Similarly, demand for specifically NM soybean amounted to about 2%; again mainly from some Japanese food importers and some EU markets. These demands were easily catered for within existing market structures, and no premium emerged for non-biotech products. But at the same time consumer trust seemed unstable. As emphasized by LCH, given consumer capriciousness it is not inconceivable that demand for GM-free products could quickly strengthen well beyond the point where the US food marketing system would prove totally inadequate.

During Spring 2000 the US domestic market, where most of the US corn and soybean harvest is consumed, seemed to be largely unconcerned about the presence of GM genes in agricultural products (Howie). However, the situation has been quite different in other countries (Gaskell). For example, many European countries, Japan, Australia, New Zealand as well as others had passed into law by late 1999 the mandatory labeling of foods produced using biotechnology. Media coverage of protests and riots during the World Trade Organization (WTO) trade talks in Seattle, December 1999, presented further manifest evidence of the uncertainty surrounding consumer acceptance of GM foods in world markets (Howie). Opposition to the growing presence of GM products in food and feed markets was a prominent motive among protestors. Events at Seattle, and also the United Nations meetings on the Cartagena Protocol in Montreal, January 2000, demonstrated that consensus among the major trading countries on labeling and other policy resolutions was unlikely to emerge soon. And this clearly worried growers in the US (McCluskey). The risk of market foreclosure must have entered the decision calculus of growers during early 2000.[5]

Another source adding to farmers' insecurity about marketability of GM varieties has come from larger food companies and grain processors' announcements on intentions to offer price premia for NM varieties or to abstain from use of GM ingredients. These included not only European, Mexican, and Japanese processors, but also US firms. For example, Archer Daniels Midland (ADM) announced in April 1999 that they would not accept EU-unapproved corn biotech varieties for processing because the opportunity to export by-products to the EU might then be foreclosed. Yet in early February 2000, when demand for premium priced NM varieties appeared weak, ADM stated that they would accept biotech varieties at no discount. As late as February 29, 2000, a national meeting of grain handlers was counseled that the decision by a single major buyer or user to turn away from GM varieties could easily cause large-scale rejection of the product (Muirhead).

Processors selling branded products directly to consumers seemed particularly wary. Gerber and Heinz food companies both declared in July 1999 that they would cease using biotech inputs in their baby foods.[6] Bestfoods Inc. announced in January 2000 that it would not use biotech ingredients in foods exported to the EU. And Frito-Lay Inc. too (February 2000) made public its intention to terminate the use of GM corn in its lines of snack foods (LCH). In addition, some grain handlers and elevators proposed contracts that made farmers liable for GM-content certification. This would have meant that the responsibility for separating NM from GM varieties would eventually rest largely with farmers. Some prominent public advisors counseled growers not to sign such contracts with grain elevators [US Department of Agriculture (2000a)].[7]

Stock market behavior provides another perspective on the uncertainty surrounding the markets for bio-engineered varieties. One of the major agricultural biotechnology innovators, Monsanto, leveraged its capital to buy seed companies during the middle and late 1990s.[8] In July 1999, the Value Line investment advice service was keen on the potential for Monsanto's line of herbicide tolerant crops but expressed concerns about the level of debt service commitments (Value Line, 1999). Yet in January 2000, the service was of the opinion that the upcoming merger with Pharmacia&Upjohn was to be welcomed in part because of " . . . , public relations setbacks for genetically modified foods and weak results for *Roundup* . . . ".[9] During the Fall of 1999, evidence of consumer resistance in Europe accumulated. Between early September 1999 and early October of that year, Monsanto's stock price fell from $60 to under $35 per share.

Of course other factors may have contributed to the grower decisions underpinning the reversal of trend seen in Table 1. The typically high levels of cross-field contamination due to pollen flows has meant that acreage under NM varieties could test positive anyway at harvest. And so neighboring growers may express concerns about a grower's use of a GM variety. Within a farm, the existence of pollen drift may lead a grower to plant all GM or none at all. There is also the concern about weed control due to volunteer herbicide resistant plants that carry over from the prior crop. Nor is this the only pest management issue that might have deterred use of GM varieties. Growers, upon re-assessing the benefits of self-insurance against pest infestations, may have concluded that the seed premium was not warranted. Further, drivers of other trends may, through linkages, affect trends in use of GM seeds. For example, no-till cultivation practices are likely positively associated with use of Roundup Ready® seeds. And some growers may also have been swayed by ethical perspectives on the new technology.[10]

But the evidence provided above about the information environment directly preceding planting time suggest that growers in Spring 2000 should have been cognizant of planting into a very uncertain demand environment for GM varieties. Indeed, a February 2000 survey sponsored by the American Corn Growers Association provides strong corroboration.[11] Of respondents, 35% asserted that they had concerns with GMOs. Of these, 70% identified the possibility of marketability problems as their main concern. In the sub-section to follow, we identify the central feature of an economic environment in which an increase in demand-side uncertainty can explain the trend reversal observed in Table 1.

Asymmetry in Substitution between Non-biotech and Biotech Varieties

One interesting feature pertaining to uncertainty of demand for GM and NM products is the nature of consumer heterogeneity (Lence and Hayes). Some consumers are indifferent about whether the product is GM or NM, while the remainder favor NM over GM foods and need to be offered a sufficient discount to purchase GM foods. This has immediate consequences for price premia. After supply is fixed at planting, it is the evolving distribution of preferences for NM over GM product among customers that governs the relative prices of NM and GM products. But there is an arbitrage bound on relative prices because indifferent consumers will eat NM foods if price falls below the corresponding price for GM foods.

Figure 1 illustrates this asymmetric relationship between prices for a NM and a GM variety. Let the supply of both products be given, and fix the post-harvest prices to be equal across varieties. After harvest, realized demand for the NM product may be low, as in outcome A where demand is less than supply. Or it may be high as in outcome B. In outcome A, where there is sufficient supply of the NM product to meet demand, the prices of NM and GM varieties must equate in equilibrium. It may seem that the price of the NM variety should fall relative to that of the GM variety. But if the price of the NM variety did fall then indifferent buyers would immediately switch from buying the GM variety to buying the NM variety and this would drive the relative price of the NM product up again. In this case, while market segregation occurs, prices are common across the markets.

In outcome B, where demand for NM product exceeds supply, the equilibrium price for the NM variety must rise above that for the GM variety in order to balance supply with demand. Consumers who are averse to GMOs express this aversion through revealed willingness to pay a premium for the NM product. Consumers who are indifferent enjoy a lower price for the GM good and have no incentive to buy the NM product. And some consumers who do care, but are not willing to pay the premium, purchase the GM product. Our model, to follow, integrates over all outcomes to establish how uncertainty about consumer demands in the post-harvest market might reflect itself in planting time decisions.

Model

Characterizing Demand

It is held that each consumer demands one unit of a commodity, and the unit can be either derived from a GM variety or from an NM variety. The consumer's utility function is given by $U(q_n, q_g)$ where consumption of the NM food is denoted by $(q_n, q_g) = (1, 0)$, and this choice generates utility $U(1,0) \equiv 1$. All consumers are common in this regard, but heterogeneity exists concerning preferences for consumption of the GM food. The decision by the consumer to use the GM variety is denoted by $(q_n, q_g) = (0,1)$, and this choice generates utility $U(0,1) \equiv \varepsilon \in [0,1]$. A consumer's heterogeneity is captured by her value of ε. The mass distribution of types along the continuum of consumers will be specified shortly, but we note for the moment that there may be a strictly positive massing at $\varepsilon = 1$.

Consumer utility is held to be quasi-linear, being linear in the income argument. Price p_n is paid for the NM variety, p_g is paid for the GM variety, while we ignore transactions costs and unit rewards to intermediaries. And so the rational consumer chooses GM if $\varepsilon - p_g \geq 1 - p_n$, while she choose NM otherwise. The threshold type is given by $\varepsilon^* = 1 + p_g - p_n$. The cumulative mass distribution of types has mixed continuous-discrete form with, possibly, strictly positive mass at $\varepsilon = 1$. It is given by $H(\varepsilon \mid \theta)$ for $\varepsilon \in [0,1)$, and 1 for $\varepsilon = 1$, where function $H(\varepsilon \mid \theta)$ will be described shortly. The distribution conditioning parameter, θ, is realized only at harvest-time, and its distribution, $R(\theta)$, characterizes the fundamental uncertainty that the grower faces at planting. We assume that $R(\theta)$ has strictly positive support on a convex interval, which we normalize to be $[0,1]$. We assume that $H(1 \mid \theta) \leq 1$, and function $H(\varepsilon \mid \theta)$ is defined on $[0, \varepsilon^+(\theta)]$ where $\varepsilon^+(\theta) = \inf_z \{z : H(\varepsilon \mid \theta) = 1\}$. But, as will become apparent, values on $(1, \varepsilon^+(\theta)]$ have little in the way of economic relevance. As illustrated in Figure 2, we assume that $H(\varepsilon \mid \theta)$ has value 0 on $[0, h_0(\theta))$, is strictly increasing on $[h_0(\theta), \varepsilon^+(\theta)]$, and is continuous. The latter condition allows that there may exist a number $H_1(\theta) < 1$ such that $H(1 \mid \theta) = H_1(\theta)$. The, possibly strictly, positive consumer mass of measure $1 - H_1(\theta)$ are held to be indifferent between varieties.

Note that $H(\varepsilon \mid \theta)$ is invertible on $[h_0(\theta), \varepsilon^+(\theta)]$, and let the inverse be given by $J(z \mid \theta) = H^{-1}(z \mid \theta)$ on $z \in [0,1]$. Now define the correspondence $T(\varepsilon, \theta) = H(\varepsilon \mid \theta)$ on $\varepsilon \in [h_0(\theta), 1)$ and $T(\varepsilon, \theta) = [H_1(\theta), 1]$ on $\varepsilon = 1$. This correspondence is not a function because $T(1, \theta)$ is not a singleton set (Mas-Colell, Whinston, and Green). Next, choose an element from the range of $T(\varepsilon, \theta)$. Observe from Figure 2 that there exists an unique element in the domain of the correspondence for each element in the range. That is, while the correspondence is not a function it is possessed of a well-defined inverse function. For $z \in T(\varepsilon, \theta)$, this inverse function is given by $J(z \mid \theta)$ on $[0, H_1(\theta))$ and 1 on $z \in [H_1(\theta), 1]$. The inverse function is given by traversing up $H(\varepsilon \mid \theta)$ to $H_1(\theta)$, and then piecing on the flat section $\varepsilon = 1$ over

$[H_1(\theta), 1]$. We hold that $J_\theta(z \mid \theta) \geq 0 \ \forall \theta \in [0, 1], \ \forall z \in [0, 1]$ so that an increase in θ (weakly) increases demand for GM.[12] Since each consumer has a fixed aggregate demand for the food and is only concerned with allocating that demand among produce that are and are not GM, an increase in θ must decrease demand for the NM variety. In Figure 2, we depict the distribution of types $H(\varepsilon \mid \theta)$ for two different realizations of parameter θ: θ_1 and θ_2, where $\theta_1 < \theta_2$. Observe that our assumptions imply that $H_1(\theta_1) \geq H_1(\theta_2)$, so that an increase in θ weakly increases the number of indifferent consumers, $1 - H_1(\theta_1)$.

Characterization of Equilibrium Supply

We now turn to the modeling of supply. For homogeneous, price-taking, and risk-neutral producers, we assume that yield, q, is common across varieties and we normalize $q = 1$ for convenience. But costs differ by variety. In particular, $c_n > c_g$ for respective per acre costs.[13] Fixing total acres under the crop to be unity, we identify x as the fraction under the NM variety. Market equilibrium, post-harvest, requires that

$$(1) \qquad x \in T(\varepsilon^* \mid \theta),$$

with correspondence inversion

$$(2) \qquad \begin{aligned} \varepsilon^* &= 1 + p_g - p_n = J(x \mid \theta), && x < H_1(\theta), \\ \varepsilon^* &= 1 + p_g - p_n = 1, && x \in [H_1(\theta), 1]. \end{aligned}$$

Viewing Figure 2, x may be modeled as an horizontal line $x = \kappa \in (0, 1]$ so that harvest-time equilibrium is given by the point where the line intersects the correspondence. Notice that, for a given value of x, the harvest-time realization of θ determines the harvest-time realization of price difference $p_g - p_n$. And, by the law of demand, $J_x(x \mid \theta) \geq 0$.[14]

The producer would derive $\pi^g = p_g - c_g$ from planting an acre of the GM variety. The return on the NM variety is at the crux of our argument because it is here that the asymmetry in demand for varieties is expressed. If it ever happened that $p_g > p_n$, then the NM grower would engage in arbitrage and divert crop into the GM market. Therefore we may write

(3) $\pi^n = \text{Max}[p_n, p_g] - c_n$

where, in contrast to π^g, we note that π^n is non-linear in output prices. Differencing, we have $\pi^g - \pi^n = c_n - c_g + \text{Min}[p_g - p_n, 0]$. Employing relation (2), we may write this difference as

(4) $\pi^g - \pi^n = c_n - c_g + \text{Min}[J(x\,|\,\theta) - 1, 0]$

where the $\text{Min}[\cdot,\cdot]$ statement captures the 'irreversibility' of not being able to sell GM varieties as NM if the market does support a price premium. This irreversibility is at the heart of our analysis, and so our model fits broadly into the literature on irreversible decisions that was initiated by Arrow and Fisher and by Henry.

Our concern is with circumstances under which there is a non-trivial probability at planting time that the post-harvest varietal prices will differ. Then there must exist a convex set of values of θ on the interior of $[0, 1]$ such that $J(x\,|\,\theta) = 1$. This set depends on acreage allocation, and we denote the infimum of the set by $\hat{\theta}(x) \in (0, 1)$. We take an expectation over Eqn. (4) to obtain the planting time expectation over the difference in harvest time profits as $c_n - c_g + \int_0^1 \text{Min}[J(x\,|\,\theta) - 1, 0]\, dR(\theta)$, where the pertinent argument of the $\text{Min}[\cdot,\cdot]$ function may be considered to switch at $\hat{\theta}(x)$. Harking back to relation (2), observe that $\hat{\theta}(x)$ is the infimum of the x-conditioned (i.e., conditioned on the division of acres planted) values of θ such that $p_g = p_n$, i.e., where the market does not support a price premium. The probability that the varietal prices differ is the x-conditioned value $R(\hat{\theta})$. When the realized at harvest value of θ exceeds $\hat{\theta}$, a decision to grow the NM variety turns out to have been an unfortunate bet because no price premium is paid for the NM variety.

In a rational expectations market equilibrium, the value of x adjusts to the $R(\theta)$-conditioned value x_r^* such that[15]

(5) $c_n - c_g + \int_0^1 \text{Min}[J(x_r^*\,|\,\theta) - 1, 0]\, dR(\theta) = 0,$

where the left-hand expression is monotone increasing in x.[16] We seek to understand how a shift in $R(\theta)$ affects equilibrium value x_r^*.

Effects of Uncertainty

The function $\mathrm{Min}[J-1,0]$ is increasing and concave in J. Further, the property 'increasing and concave' is preserved under composition.[17] And so, if $J_{\theta\theta}(x\,|\,\theta) \le 0$ then the left-hand side of equality (5) is increasing and concave in θ. Consequently, if the map $R(\theta) \to R^1(\theta)$ represents a second-degree stochastically dominating shift, denoted by $R^1(\theta) \overset{ssd}{\geq} R(\theta)$ and abbreviated as SSD, then the left-hand side of (5) increases.[18] To re-establish equilibrium, the rational expectations equilibrium value x_r^* must fall.[19]

PROPOSITION 1. *Suppose that* $J_{\theta\theta}(x\,|\,\theta) \le 0$ $\forall\, \theta \in [0,1]$, $\forall\, x \in (0,1]$. *Then equilibrium acreage allocated to variety NM decreases under a SSD shift* $R(\theta) \to R^1(\theta)$.

The adjustments that occur in Eqn. (5) act to preserve the expected difference in output prices given the arbitrage opportunity. This can be seen quite clearly through an example.

EXAMPLE. Let $H(\varepsilon\,|\,\theta) = H(\varepsilon - \theta)$ so that $\varepsilon^* - \theta = 1 + p_g - p_n - \theta = Y(x)$ where relation (2) requires that $Y(x) = J(x\,|\,\theta) - \theta$. Now we can write Eqn. (5) as

$$(6) \qquad c_n - c_g + \int_0^1 \mathrm{Min}[Y(x_r^*) + \theta - 1, 0]\, dR(\theta) = 0,$$

and the Proposition holds because of the linearity of $J(x\,|\,\theta)$ in θ. An integration by parts, together with a cancellation, yields $\int_0^1 \mathrm{Min}[Y(x_r^*) + \theta - 1, 0]\, dR(\theta) = -\int_0^{1-Y(x_r^*)} R(\theta)\, d\theta$. If we write $x_r^* \to x_{r1}^*$ as the shift in equilibrium acres planting corresponding to $R(\theta) \to R^1(\theta)$, then Eqn. (6) requires that $\int_0^{1-Y(x_r^*)} R(\theta)\, d\theta - \int_0^{1-Y(x_{r1}^*)} R_1(\theta)\, d\theta$ remain fixed after the stochastic shift. By the definition of SSD, we have $\int_0^{1-Y(x_r^*)} R(\theta)\, d\theta \ge \int_0^{1-Y(x_r^*)} R_1(\theta)\, d\theta$. And so it is required that $\int_{1-Y(x_{r1}^*)}^{1-Y(x_r^*)} R_1(\theta)\, d\theta \le 0$, i.e., that $x_r^* \ge x_{r1}^*$.

Notice that assumption $J_{\theta\theta}(x\,|\,\theta) \le 0$ is necessary because we do not know whether the shift in weightings on θ presents itself on $[0,\hat{\theta}(x_r^*))$ only, on $[\hat{\theta}(x_r^*),1]$ only, or across both intervals. Suppose that it presents itself on $[0,\hat{\theta}(x_r^*))$ only, so that the relevant argument in Eqn. (5) is $J(x_r^* \mid \theta) - 1$. In this case, if $J(x_r^* \mid \theta)$ were *strictly* convex in θ then the result in Proposition 1 would be reversed. Put another way, we need to know what effect a risk shift will have when arbitrage is not allowed before we can infer what will happen when we admit the possibility of arbitrage. As to what $J_{\theta\theta}(x \mid \theta) \le 0$ means, remember that a larger realization of θ represents a shift in the distribution of preferences toward GM. If $J(x \mid \theta)$ is concave in θ then the effect of a larger θ, given by $J_\theta(x \mid \theta)$, is declining in the value of θ. There is an asymmetry; an increase in θ, $\Delta\theta > 0$, has less upside impact on demand for GM than the corresponding downside impact on demand arising from decrease $-\Delta\theta$. Demand does not expand by as much under good news about GM as it would contract under an equal magnitude of bad news.

A second point to note is that the effect on the probability of a price premium emerging is indeterminate under an arbitrary shift $R^1(\theta) \overset{ssd}{\ge} R(\theta)$. Since x^* decreases (weakly), we can infer that $\hat{\theta}$ increases. But $R^1[\hat{\theta}(x_{r1}^*)] - R[\hat{\theta}(x_r^*)]$ can be of either sign. Using the technology in the example, we presently pursue the issue of how the nature of uncertainty affects the probability of a price differential at harvest. To do this, we find it convenient to fix $R(\theta)$ and, instead, alter (map) the consequences of any given draw on θ. This mapping approach facilitates accounting in the analysis because under it we only need to establish what happens to $\hat{\theta}$ in order to know what happens to $R(\hat{\theta})$.

In Eqn. (6) we have that $\hat{\theta} = 1 - Y(x^*)$ where the subscript on acres has been removed because we have fixed in on a given $R(\theta)$. Now represent the change in distribution by a deterministic map in the manner of Ormiston; $\theta \to \theta + bk(\theta)$ where $b \ge 0$ parameterizes the extent of the shift. And so $\hat{\theta}$ becomes the solution to the switching equation

$$(7) \qquad \hat{\theta} + bk(\hat{\theta}) = 1 - Y(x^*),$$

with equilibrium determined as the acreage solving

$$(8) \qquad c_n - c_g + \int_0^1 \mathrm{Min}[Y(x^*) + \theta + bk(\theta) - 1, 0]\, dR(\theta) = 0.$$

Meyer has shown that an increase in the value of b generates a SSD shift in the distribution of θ if and only if $\int_0^{\hat{\theta}} k(\theta)\, dR(\theta) \geq 0 \;\; \forall\, \hat{\theta} \in [0,1]$. Defining $m(\hat{\theta}) = \int_0^{\hat{\theta}} k(\theta)\, dR(\theta) / R(\hat{\theta})$, work presented in the Appendix leads us to

PROPOSITION 2. *Suppose that* $J(x \mid \theta) = Y(x) + \theta$, *and that* $\int_0^{\hat{\theta}} k(\theta)\, dR(\theta) \geq 0 \;\; \forall\, \hat{\theta} \in [0,1]$. *Then the probability that a market price differential emerges increases (decreases) with a small increase in index b if $m(\hat{\theta})$ is decreasing (increasing).*

For $m(\hat{\theta})$ a decreasing function, the proposition requires that shift $k(\theta)$ be decreasing, at least on the average, as θ increases. Low θ tend to be increased by most under that type of map. And

if any θ are reduced in value under that type of map they tend to have high initial values. Fixing x^*, it might seem that $\hat{\theta}$ should decrease to offset the overall rightward distribution shift. But Proposition 1 relates that x^* decreases and, by itself, this suggests that the $\hat{\theta}$ threshold should increase so that the probability of a price differential increases. The effect of map $\theta \to \theta + bk(\theta)$ on $\hat{\theta}$ depends on a single evaluation of the map, namely $\hat{\theta} + bk(\hat{\theta})$. But, as can be seen from (8), the effect on x^* depends, by contrast, on all evaluations of the map on $[0, \hat{\theta}]$. A differentiation of $m(\hat{\theta})$ reveals how these two offsetting forces are accommodated in the criterion; $k(\hat{\theta})$ represents the effect on the threshold and $\int_0^{\hat{\theta}} k(\theta)\, dR(\theta) / R(\hat{\theta})$ represents the effect on x^*.

Preferences over Information Environments

Now suppose that, for a given $R(\theta)$, more information can be obtained before planting so that the quality of planting time decisions can be improved upon. For example, it may become known that the EU Parliament will vote on legislation concerning the regulation of GMOs before April planting rather than later. While more information is always to be preferred, decision makers will have preferences over the sorts of clarification on issues that are on the agenda to emerge.

We seek to understand what sorts of distributions on signals growers would like to draw from prior to making the irreversible planting decision. And also, to understand what effects a preferred distribution on signals might have on the nature of planting decisions made. The seminal analysis in this area is the extension by Athey and Levin of Blackwell's work on comparisons of experiments. Their extension identifies a relationship between the incremental returns arising from information-conditioned decisions and the underlying information environment.

Incremental Returns

The price-taking grower's decision variable is a binary choice variable, which we label as a, drawn from the binary set $\{0, 1\}$ where $a = 1$ signifies an acre allocated to GM. Absent a signal, the grower's decision problem is to choose $a \in \{0, 1\}$ to maximize the expected value of

$$(9) \qquad (p_g - c_g)a + (\text{Max}[p_n, p_g] - c_n)(1 - a).$$

The state-contingent effect of decision increment $[a = 0] \rightarrow [a = 1]$ is $c_n - c_g + \text{Min}[p_g - p_n, 0]$, i.e.,

$$(10) \qquad c_n - c_g + \text{Min}[J(x^* | \theta) - 1, 0].$$

We identify this expression as the grower's *incremental return function*. In Proposition 1 above, we have already observed conditions under which expression (10) is concave in θ. We will shortly show that these conditions are also central to identifying the nature of an information structure that is more valuable to growers.

Information Structures

In seeking to explain an information structure, it might be best to assume that there are four successive time points of interest; points 0, 1, 2, and 3. Time points 2 and 3 are planting time and harvest time. Time point 0 is the present, namely some time before sowing. At intermediate time point 1, information (i.e., signals) will be revealed about the nature of demand that the grower will sow into. The set of time point 1 signals concerning the value of

θ is represented by $\zeta \in Z$, and the ex-ante joint distribution of the random variables is $F(\zeta,\theta)$: $Z\times[0, 1] \rightarrow [0, 1]$. This is the grower's information structure, and a set of signals containing different information on the given prior, $R(\theta)$, would have to be represented by a different information structure. Denote by $F_Z(\zeta \mid \theta)$ the state-conditioned distribution of the signal, and denote by $F_\Theta(\theta \mid \zeta)$ the grower's posterior belief about the distribution of θ after having observed the signal realization ζ. Finally, describe by $F_Z(\zeta) = \int_0^1 F_Z(\zeta \mid \theta) dR(\theta)$ the marginal distribution of signals. The distribution of signals is of value to the grower because it allows choice a to be conditioned on distribution $F_\Theta(\theta \mid \zeta)$, for each realized signal ζ, rather than on the prior.

Now let there exist an alternative information structure $\hat{F}(\zeta,\theta)$: $Z\times[0, 1] \rightarrow [0, 1]$ with the same prior but different signal-conditioned posterior distributions on the prior. The question that Blackwell answered was how the information structures should relate so that a decision-maker with arbitrary loss function would have ordered preferences over the structures.[20] However, the generality of the set of loss functions under scrutiny rendered a very incomplete partial ordering over information structures. Following on work by Lehmann, the contribution of Athey and Levin has been to refine the analysis of orderings on information structures to focus on the classes of functions of most interest to economists. In reducing the set of functions under scrutiny, much of the incomparability in the partial ordering can be resolved and the ordering becomes more complete. Because of the nature of expression (10), the set of functions pertinent to this study is the set of increasing and concave functions.

Value of Information

When comparing information structures, the primary statistical attribute of relevance is $F_\Theta(\theta \mid F_Z(\zeta) \geq t)$. To interpret this function, first choose some $t \in [0, 1]$. Then identify the set of signals $\zeta \in Z$ from the marginal distribution of signals $F_Z(\zeta)$ such that $F_Z(\zeta) \geq t$. For concreteness, let $Z = [0, 1]$ so that the signal set in question is of the form $[F_Z^{-1}(t), 1]$.[21] Next, suppose that all one knows is that $\zeta \in [F_Z^{-1}(t), 1]$. Given this rather coarse information, one can update the unconditional prior $R(\theta)$ to obtain the posterior $F_\Theta(\theta \mid F_Z(\zeta) \geq t)$ on the distribution of θ. Athey and Levin show that if

$$\text{(MIO)}\quad \begin{array}{l} F_\Theta(\theta \mid \zeta') \overset{ssd}{\geq} F_\Theta(\theta \mid \zeta) \quad \forall \zeta' \geq \zeta, \quad \hat{F}_\Theta(\theta \mid \zeta') \overset{ssd}{\geq} \hat{F}_\Theta(\theta \mid \zeta) \quad \forall \zeta' \geq \zeta, \\ \hat{F}_\Theta(\theta \mid \hat{F}_Z(\zeta) \geq t) \overset{ssd}{\geq} F_\Theta(\theta \mid F_Z(\zeta) \geq t) \quad \forall t \in [0,1], \end{array}$$

then all decision makers with incremental return functions that are increasing and concave in θ will prefer information structure $\hat{F}(\zeta,\theta)$ over $F(\zeta,\theta)$.[22] The second line in MIO has already been explained. The first line merely clarifies what constitutes a good signal, at least so far as changes in actions are concerned.[23]

Now, returning to expression (10), the reasoning behind Proposition 1, and the Athey-Levin finding concerning MIO, we deduce

PROPOSITION 3. *Suppose that* $J_{\theta\theta}(x \mid \theta) \leq 0$. *If information structures* $\hat{F}(\zeta,\theta)$ *and* $F(\zeta,\theta)$ *are ordered according to MIO, then a price-taking grower will prefer* $\hat{F}(\zeta,\theta)$ *over* $F(\zeta,\theta)$.

To see why grower preferences are thus, let us focus on the $\overset{ssd}{\geq}$ relation in the lower line of the MIO ordering. Over the same set of high-end percentile (i.e., $\zeta \in [F_Z^{-1}(t),1]$) draws on the signal, the preferred information structure presents rightward (on the average) and less risky (on the average) signal-conditioned distributions for state variable θ. For high realizations of θ, Eqn. (5) and condition $J_\theta(x \mid \theta) \geq 0$ relate that a GM grower would consider herself to have been relatively fortunate (or wise) to have chosen GM over NM.

Viewed in this light, it is more apparent why the distributions associated with high signals should be less risky. The GM grower does not have the risk management option to arbitrage GM yield into the NM market if the market prices do differ. For the grower seeking further information before planting, an information structure under which pre-planting signals suggesting an high, but relatively dispersed, value on θ would not be all that helpful in guiding the grower toward either variety. Neither, for that matter, would a signal suggesting a low θ with low dispersion.

More helpful would be a signal suggesting a posterior on θ such that the realization is likely to be high and possessed of comparatively low dispersion. In the event of these high draws, the grower will gravitate towards planting GM varieties. More helpful also would be a signal suggesting a posterior on θ such that the realization is likely to be low and possessed of comparatively high dispersion. Then the grower will gravitate toward planting NM varieties, and the reasoning is quite intuitive. At the grower level, revenue on an acre of an NM variety is not at all vulnerable to demand-side risk because any price discounting that emerges will not be against the NM variety. For an information structure to be preferred, then any signal suggesting a lower draw on θ should, in general, also suggest a more dispersed draw on θ. Given a fixed amount of risk in the prior, the posteriors should bias the risk toward the NM decision.

To conclude our analysis, we seek to integrate the findings in Propositions 1 and 3. Define a signal under information structure $F(\zeta,\theta)$ as HIGH if $F_Z(\zeta) \geq 0.5$, i.e., $t = 0.5$. Otherwise, define it as LOW. Now provide, instead, all growers with the coarsened signal of (HIGH, LOW) for either information structure, and call these information structures $F(\{H,L\},\theta)$ and $\hat{F}(\{H,L\},\theta)$. This coarsening might occur as media that extend market analyses seek to aggregate information and simplify innovations on a complicated story. In contrast with Proposition 3, in our final result we seek to understand behavior under different given information structures rather than preferences over information structures.[24]

PROPOSITION 4. *Suppose that* $J_{\theta\theta}(x\,|\,\theta) \leq 0$. *Also, let information structures* $\hat{F}(\zeta,\theta)$ *and* $F(\zeta,\theta)$ *be ordered according to MIO. If the growers were to observe only* $\hat{F}(\{H,L\},\theta)$ *and* $F(\{H,L\},\theta)$, *then*

a) *equilibrium acreage allocated to variety NM is smaller under signal H in information structure* $\hat{F}(\zeta,\theta)$ *than under H in* $F(\zeta,\theta)$, *and*
b) *equilibrium acreage allocated to variety NM is larger under signal L in information structure* $\hat{F}(\zeta,\theta)$ *than under L in* $F(\zeta,\theta)$.

The Proposition suggests that the MIO order *may* tend to have market stabilizing effects because it, in a sense, induces a dispersion on the decisions made. Low acreage allocations are lower and high acreage allocations are higher under $\hat{F}(\{H,L\},\theta)$ than under $F(\{H,L\},\theta)$. The Proposition suggests that a low percentile signal draw under $\hat{F}(\zeta,\theta)$ may be better at guiding acres toward NM than would generally be the case for a low percentile draw under $F(\zeta,\theta)$. Ex-poste, if the LOW signal were warranted then the additional product is available to sate demands by GM averse consumers, thus stabilizing markets. In the extreme, if $\hat{F}(\zeta,\theta)$ provides complete information then θ becomes known before planting and, for an interior solution, Eqn. (5) degenerates to $c_n - c_g = 1 - J(x^* \mid \theta)$ so that $dx^*/d\theta \le 0$. This trivial case is consistent with Proposition 4.

Conclusions

This paper has inquired into the equilibrium effects of uncertainty about, and information signals on, the distribution of attitudes towards GM foods. While our model does admit conditions under which increased demand uncertainty elicits an increase in equilibrium acreage under GM varieties, it is more likely that the relationship is negative. The strength of any such negative response may be lessened by the existence of other approaches to satisfying sudden shifts in consumers' preferences. A change in trade partners and international trade flows is, perhaps, the most important alternative approach. This pathway, while not considered in our analysis, warrants inquiry.

Nonetheless, the problem we do address is not one of transitory interest. The situation where the degree of consumers' acceptance of a new technology in food production is unknown in advance is not confined to crop agriculture. Whenever public acceptance of the new technology, delivering product that has effectively the same physical and chemical attributes as the standard technology, is in question then a problem similar to the one we have analyzed will be countenanced. Consumer and activist pressure has been felt in recent years by major fast-food retailers concerning the treatment of animals on farms they source from.[25] Food marketers may have incentive to capitalize on such consumer preferences by advertising their product as free from offending practices. If such preferences strengthen, and they would appear to be income elastic, then market segmentation and price premia may evolve to support "ethically" produced raw inputs. As the markets evolve, however, there will be time intervals when producers will have to make investments, in say animal housing, that consumers may subsequently reject.

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Appendix

From a differentiation of equilibrium condition (8) we have

$$\text{(A1)} \qquad \frac{dx^*}{db} = -\frac{\int_0^{\hat{\theta}} k(\theta)\, dR(\theta)}{Y_x(x^*) R(\hat{\theta})}.$$

Differentiating switching Eqn. (7) completely with respect to $(\hat{\theta}, b, x^*)$, then evaluating at $b = 0$, and using (A1), yields

$$\text{(A2)} \qquad \frac{d\hat{\theta}}{db} = \frac{\int_0^{\hat{\theta}} k(\theta)\, dG(\theta)}{R(\hat{\theta})} - k(\hat{\theta}) = -\frac{R(\hat{\theta})}{r(\hat{\theta})} \frac{dm(\hat{\theta})}{d\hat{\theta}},$$

where $r(\theta) \equiv dR(\theta)/d\theta$. And so $d\hat{\theta}/db$ has the sign of $-dm(\hat{\theta})/d\hat{\theta}$, i.e., $dR(\hat{\theta})/db$ has the sign of $-dm(\hat{\theta})/d\hat{\theta}$.

Table 1. Percent of Acres Allocated to Crops from GM Seed in the US

Crop	1996	1997	1998	1999	2000
Corn	1.4[a]	8.1[a]	19.1[a]	37[a] 35[b]	25[a] 26.5[b]
Soybeans	7.4[a]	17[a]	44.2[a]	57[a]	54[a]
Cotton	14.6[a] 13[c]	25.5[a] 17[c]	38[c]	55[c]	61[a] 72[c]

[a] USDA estimates of adoption rates from 1996 to 1999. For 1996-98, see USDA (2000b). For 1999, see USDA (1999). For 2000, see USDA (2000c).

[b] National Corn Growers Association.

[c] James.

1. Other works (see, e.g., Hubbell, Marra, and Carlson, and also Lapan and Moschini) have studied grower adoption of GM seeds but not the role of uncertain consumer acceptance in that decision. While Lence and Hayes have modeled the demand asymmetry that we will model, they do not consider uncertainty. Instead, they focus on welfare issues.

2. Genetic engineering is a technique used to modify or reposition genetic materials of living cells [US Department of Agriculture (2000a)]. Narrower definitions are used by agencies that regulate GM organisms (GMO). Under the USDA's Animal and Plant Health Inspection Service guidelines, genetic engineering is defined as the genetic modification of organisms by recombinant DNA techniques. But definitions are not uniform across countries.

3. Adoption rates in the earlier years have been largely determined by the limited supply of new GM seeds (Carlson, Marra, and Hubbell). Historically, Roundup Ready® soybeans have been more attractive than GM corn: at first due to larger cost reductions and cheaper seeds, and later as a result of a wider public acceptance.

4. With a yield of 45 bushels/acre, the differences between GM and NM soybeans production costs/ acre were comprised of: (i) pre-harvest machinery: $22.06 (NM) and $19 (GM), (ii) seed: $18.00 vs. $25.20, (iii) chemicals: $65.75 vs. $60.95, (iv) labor: $18.99 vs. $17.44, (v) interest: $5.69 vs. $5.78. Total cost per acre of NM soybeans exceeds that of GM soybeans by $2.12. Cost advantages (i), (iii), and (iv) have almost certainly persisted into planting year 2001 (Duffy and Smith, 2000b). Note also that these budgets do not include the reduction in the management time commitment associated with the GM variety, and so the difference in economic cost is larger than the accounting difference reported above.

5. Alexander and Goodhue (2000) surveyed Iowa Farm Bureau members in Spring 2000. Among respondents that had planted corn in 1999 and intended to do so in 2000, 15% had (4% had not) grown GM corn in 1999 but did not (did) intend to do so in 2000. Among responding soybean growers, 9% had (4% had not) grown GM soybean in 1999 but did not (did) intend to do so in 2000. In each case intended reversion by adapters exceeded intended new adoptions.

6. Gerber is owned by Novartis, a significant player in global GM seed and technology markets.

7. As one alternative, the office of the Iowa Attorney General, together with Iowa State University, disseminated a voluntary uniform certification whereby the grower affirmed the varieties grown and attested that negligence in care against contamination did not occur when the crop was being harvested, stored, or transported by the grower (Doane's Agricultural Report).

8. On March 31, 2000, Monsanto merged with Pharmacia&Upjohn, Inc. to create Pharmacia Corporation. Monsanto was not a pure play in agri-biotech, because approximately 50% of its 1999 sales came from food additives and pharmaceuticals.

9. On March 31, 2000, Monsanto merged with Pharmacia&Upjohn, Inc. to create Pharmacia Corporation. Monsanto was not a pure play in agri-biotech, because approximately 50% of its 1999 sales came from food additives and pharmaceuticals.

10. In addition to religious concerns, scientific and media attention has been directed towards the possibilities of negative externalities on pest resistance, wildlife vitality, and human health.

11. A total of 582 randomly selected growers from 17 states were surveyed.

12. Throughout, please read 'increasing' and 'decreasing' to be non-strict properties. Also, the properties 'concave' and 'convex' admit linearities. The intuition that demand increases should be

clear, but a formal demonstration hinges on the observation that $J_\theta(z \mid \theta) \geq 0$ implies that the function $Min[J(z \mid \theta) - 1, 0]$ is increasing in θ. This latter function will be countenanced shortly.

13. Please see footnote 4 above.

14. As we have assumed weak monotonicity for both arguments of $J(x \mid \theta)$ any inferences we develop are also weak. But we will remind the reader of this upon occasion.

15. Actually, the weak assumption $J_x(x \mid \theta) \geq 0$ implies that there may exist a non-singleton set of x values satisfying Eqn. (5). As with theta hat (x) above, we take the set infimum and establish monotonicity for it. An alternative approach would be to use, as Milgrom and Shannon (1994, p. 159) did, Veinott's strong set order when comparing sets of solutions to (5). Set monotonicity analogs exist for all the results we will establish.

16. It should be noted that a rational expectations equilibrium holds that growers have a good idea about the neighborhood that x seems to be settling towards when they plant. This seems plausible given that planting date can vary by up to a month across the US for corn and soybeans, and that seed companies induce growers to place orders several months before planting.

17. For $x \in X$, property P is preserved under composition if $h(x) = g(f(x))$ possesses P on $x \in X$ whenever a) $f(x)$ possesses P on $x \in X$, and b) $g(z)$ possesses P on $z \in f(X)$.

18. On stochastic dominance, see, e.g., pp. 92–95 in Copeland and Weston.

19. Of course, a mean-preserving contraction is a particular sub-class of SSD shifts in R(theta).

20. Actually, the set of loss functions Blackwell considered is not quite arbitrary. Each member must be measurable with respect to the σ-algebra on which the distributions are defined.

21. In this illustration, if the inverse correspondence is not unique then take the infimum of $\{\zeta : F_Z(\zeta) = 1\}$.

22. As Babcock has pointed out, market-level effects can overturn inferences about the value of information that are developed at the firm level.

23. Of course, ζ under information structure $F(\zeta, \theta)$ and ζ under $\hat{F}(\zeta, \theta)$ should not be compared across information structures. Cardinalization, via calibration according to quantiles, does admit comparison across information structures.

24. To establish Proposition 4, use MIO to make the observation that if H is drawn under both information structures then the posterior under $\hat{F}(\{H, L\}, \theta)$ SSD dominates the posterior under $F(\{H, L\}, \theta)$. Then apply Proposition 1.

25. As a case in point, in August 2000 McDonald's Corp. announced a code of conduct on animal welfare to be adhered to by their egg suppliers. Shortly thereafter PETA, an organization seeking improved conditions for animals, announced that it would place a moratorium on a planned publicity campaign against the company (Smith).

CHAPTER 5. VOLUNTARY NON-GMO LABELING IN A TWO-STAGE PRODUCTION ENVIRONMENT

A paper to be submitted to a journal in the field

Alexander E. Saak

Abstract

This paper inquires into the market differentiation between genetically modified (GM) and non-GM food varieties in a two-stage production environment. In the first stage, acres are allocated between GM and non-GM crop varieties. In the second stage, the share of non-GM variety that is processed separately from the GM variety is established. Having observed high demand for non-GM food variety, some food processors may falsely label their product as non-GM. Contrary to intuition, the amount of fraud may not fall as a result of enhanced monitoring efforts, higher penalties, or a rebate on the cost of the investment in the segregation. In part two of the paper, the uncertainty about consumer acceptance of GM foods, penalty, and segregation costs, which is not fully resolved until after production decisions have taken place, is introduced. The effects of an increase in uncertainty on the level of segregation and acreage allocation are investigated. We find plausible conditions such that the level of segregation and acres sown to non-GM variety fall when there is a reduction in information available at harvest and planting.

Introduction

As of the time of this writing, the use of biotechnology in food production continues to be a controversial issue. One of the concerns raised in the literature is whether some form of government intervention into the market provision of information related to the use of biotechnology is expedient. As in any other market, asymmetric information about food production practices, where producers know more than consumers, creates incentives for fraud and leads to market inefficiency.

Ideally, in a world absent of transactions costs, a consumer should have access to all information relevant to the product. A production process used to derive a product can be an important attribute.[1] To create an environment where fully informed consumption decisions are made, such data need to be provided routinely. On these grounds, a mandatory labeling policy specifying the genetically modified organisms (GMO) content of the ingredients used in food preparation is often advocated.[2] However, without a heavy investment in the necessary infrastructure, attempts to guarantee accurate and verifiable GMO labels can prove to be costly. The predominant opinion seems to be that, in theory, apart from difficulties arising due to information asymmetry and some distributional concerns, market-driven differentiation between non-GMO and GMO products appears to be efficient (e.g., Ballenger, Bohman, and Gehlhar (2000)). In this study, we focus on the consequences of information asymmetry when it takes the form of false labeling of a final food product in a general equilibrium framework.

Motivation and Background

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 specified that the FDA does not consider "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 labeling of all bio-engineered foods" (FDA's *Guidance for Industry*).[3] 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 (2000a) 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.

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[1] We do not address the argument that a production method (including biotechnology) may be irrelevant to the safety of human consumption or any other product characteristics.

[2] Technically, the presence of GMOs does not imply the use of biotechnology. For a discussion of a common misusage of this terminology see FDA's *Guidance for Industry*.

[3] 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.

For example, according to Callahan and Kilman (2001), about 40% of soybeans DNA in a sample of "non-GMO" veggie bacon produced by Yves Veggie Cuisine, a Canadian maker of vegetarian dishes, were detected to be genetically modified. These authors document a number of other cases of inadequate "GMO-free" labeling as well.

Food items produced with or without the use of biotech ingredients are examples of *credence* goods because consumers cannot determine which technology was used to derive a product (e.g., see Caswell and Mojduszka (1996)). While there is rich literature on credence goods and fraudulent behavior caused by asymmetric information, there have been relatively few theoretical studies focusing on *competitive food markets* for credence goods. The following section contains a synopsis of the relevant literature. Generally, the papers, pertinent to this study, appear to fall into four broad categories that will be discussed in turn. A large share of the growing literature on agricultural biotechnology has been devoted to the discussion (relying largely on verbal arguments) of current food labeling regulations and the real-world's market differentiation between non-GMO and GMO food varieties. Also, a number of papers present more formal inquiries into the issues related to food safety (or organic food) provision in the presence of asymmetric information. Valuable insights delivered by this literature offer a useful benchmark for assessing the policy implications derived in this paper. In addition, our approach draws on some of the literature on credence goods and on the economics of law enforcement.

Literature Review

There is an impressive body of accumulated research analyzing the institutional character of problems posed by the use of biotechnology in food production. To name just a few, Bhatia and Powell (2000) compile a comprehensive survey of recent approaches to the mandatory vs. voluntary GMO labeling debate that were adopted in different countries and the international trade arena. A dichotomy of various types of risks and uncertainties associated with biotech foods (credence goods) is provided in Phillips and Isaac (1998). They indicate that particular labeling policies may lead to the overproduction (underproduction) of biotech foods.

A study by Guru and Horne (2000) contains an overview of U.S. food labeling laws and regulations and presents an interesting comparison of the labeling issues for GMO and organic foods in the U.S. and the European Union. A thorough and very insightful description of the U.S. grain production and food marketing system can be found in Bullock, Desquilbet and Nitsi (2000). They provide a detailed and extensive picture of the institutional set-up of world grain markets and marketing channels along with many empirical estimates of price premiums and identity preservation costs, including the costs of purity testing, shipping, and segregation in various stages of the food supply chain.

Caswell (1998a) and (2000) builds a solid rationale for the "benefits and costs" approach to searching for a welfare-improving food labeling policy. Caswell (1998b) emphasizes that mandatory labeling is likely to impose a higher cost since the entire market must be segregated and labeled even though only a portion of consumers favor non-GMO foods. In a similar vein, Runge and Jackson (1999) strongly advocate "negative" labels ("this product contains no GMOs") as an alternative to "positive" labels ("this product may contain GMOs"). They also emphasize a need for a regulatory system to "assign, define and enforce such a label." On the other hand, McCluskey (2000b) argues that the additional costs imposed by mandatory labeling must be weighed against its appealing political aspect which comes to the forefront when a majority of consumers are concerned with biotech attributes. However, the analysis by Miller and VanDoren (2000) accentuates the role of competitive markets in product differentiation and information provision, and concludes that there is no pressing need for government intervention in U.S. biotech food markets. A discussion of questions regarding the estimation of the welfare effects of labeling policy in a general setting can be found in Teisl and Roe (1998).

Analysis of food safety regulations focusing on differentiation between internal penalties (imposed by the regulator) and external penalties (imposed by the market or by the court) is performed in Starbird (2000). The author indicates that internal penalties for noncompliance may in some cases be superior to market- or court-imposed penalties.

McCluskey (2000a) develops a game theoretic approach to the analysis of asymmetric information and policy in credence goods market. She shows that, typically, market inefficiency caused by asymmetric information about production practices can be resolved through third-party (either private or government) monitoring with repeat-purchase relationships. A formal modeling of "mandatory versus voluntary approaches to food safety" is provided in Segerson (1999).[4] She shows that, even in the case of credence goods (which implies the absence of market-driven incentives to invest in food safety), firms might choose to invest voluntarily if induced to do so by a "carrot" or "stick" administered by the government. Marette, Bureau, and Gozlan (2000) examine economic mechanisms related to the provision of product safety under different structures of consumers' information. They assume that consumers cannot observe production choices and conclude that imperfect information leads to a market closure in the case of credence goods and no government intervention. In their approach, minimum safety standards and verifiable labeling are the recommended policy measures to avoid market failure.

The last three papers fit broadly into the literature on credence goods pioneered by Darby and Karni (1973). They examine how demand conditions, production technology and reputation affect the equilibrium amount of fraud in competitive markets for expert services where "diagnosis" and "repair" are jointly supplied. The "fraudulent expert" problem has been further analyzed by Pitchik and Schotter (1987), Wolinsky (1993), Taylor (1995), Emons (1997), Emons (2001) and others. Their illuminating contributions take a game-theoretic approach and show how markets for credence goods fare in a variety of institutional settings ranging from the multiple opinions mechanism to long-term maintenance agreements. The papers by Emons are somewhat closer to our model in that he takes consumers to rationally process ex-ante information about capacity choices. Importantly, in our set-up, consumers know their type (or in terms of the "fraudulent expert" problem, the exact condition of a product and not just the probability that the product needs "repair") and, therefore, always discard "diagnosis". Feddersen and Gilligan (2001) provide a very interesting theoretical exploration of the potential effects of an information-supplying activist on a market for credence goods. Similar to our analysis, their consumers are concerned with

[4] Throughout the paper, we consider process-based GMOs where biotechnology enhances input traits such as productivity or yield of a product (e.g., RoundUp Ready or Bt varieties of corn, soybeans, canola, and cotton). Importantly, such use of biotechnology does not alter the output traits of a product, therefore making it impossible to differentiate GMO food varieties from non-GMO varieties if there is a mixed and unlabeled supply of both types of commodities. Given the nature of consumer preferences, non-GMO food can then be broadly identified with "safe" food.

a firm's operating practices that are difficult to observe. However, in our case, a monitoring agency, instead of providing a source of information for consumers, is capable of imposing *fines* on producers falsely purporting their production practices.

The presence of a monitoring (government) agency penalizing false labeling allows us to draw analogies with vast literature on optimal regulation. A majority of that literature is dedicated to seeking the most efficient policy to correct for an externality due to hazardous activities.[5] To see the connection, in our model, cheating suppliers impose an externality on consumers and honest suppliers because consumers' valuation of a possibly falsely labeled product is lower. Finally, in the spirit of law enforcement literature, we will differentiate between ex-ante (act-based) and ex-post (harm-based) penalty (sanction).

The formal model presented in this paper appears to be related to the literatures on food safety, credence goods and law enforcement but it differs in several important aspects. First, we explicitly highlight the role of information asymmetry for *labeling and segregation* decisions in a competitive equilibrium. Second, we allow consumers to *rationally estimate* the average "quality" (proportion of non-GMO and GMO ingredients used to derive a product) by observing the aggregate production decisions. Third, we assume that consumers rely on a (government) monitoring agency to identify and *penalize* false labeling.[6] Fourth, we investigate the effects of *uncertainty* related to the distribution of consumer preferences and the production environment on equilibrium outcomes.

Before we proceed further, we need to precisely define what constitutes a fraudulent label in the context of non-GMO food labeling. Two distinct approaches are possible (e.g., see Wittman (1977)). An "ex-ante" definition of false labeling, primarily used in this paper, is more restrictive and states that a label is false if a food item is labeled as non-GMO *without the exact knowledge* that the item has a zero GM-content. Therefore, even if a product happens to be GMO-free, the act of cheating is considered to have taken place. According to the "ex-post" definition, a product is falsely labeled as non-GMO only if *it is*

[5] Some of the recent literature on law enforcement includes Shavell (1991) studying the trade-offs between general and specific enforcement effort, Polinsky and Shavell (1992) investigating the magnitude and probability of optimal fines, Shavell (1993) inquiring into ex-ante (previolation) and ex-post (postviolation) regulation, Kaplaw and Shavell (1994) examining self-reporting behavior, and Lott (1996) looking into the effects of reputation on fraudulent behavior.

[6] Perhaps, a law enforcement agency utilizes economies of scope to lower the costs of monitoring and collecting fines from the violators.

revealed to possess a GM substance. Both definitions have their virtues and drawbacks. On the one hand, the "ex-post" definition is more internally consistent with the assumption of risk-neutral consumers adopted in this paper.[7] On the other hand, the "ex-ante" definition is likely to be more appealing in real world situations.[8] It will be shown that the recommendations for anti-false labeling policies are likely to differ somewhat depending on the definition used.

In a similar vein, the penalty can target either "ex-ante" or "ex-post" false labeling. In this paper, we focus on the case where the goal and the instrument are misaligned in the following sense. The government's objective is to reduce the share of "ex-ante" false labels, i.e., food products labeled as non-GMO that could *possibly* contain non-trivial traces of GM substances. However, to achieve that objective, the government imposes a penalty on those producers who are caught supplying products that have been labeled as non-GMO but *are detected* to belong to the GMO variety. While the choice of a government's objective is an unresolved and hotly debated political issue, it seems that a large number of incidences of false labeling are discovered and penalized "after the fact" (i.e., only if non-GMO labeled food has been detected to contain GM ingredients).[9] In addition, this particular pair of the "ex-ante" objective and the "ex-post" instrument yields somewhat simpler analytical manipulations. In any event, analyzing other combinations of goals (reduce "ex-ante" or "ex-post" false labeling) and instruments (penalize "ex-ante" or ex-post" false labeling), typically, produces results parallel to those found in this paper.

The penalties for "ex-ante" and "ex-post" false labeling can be broadly identified with "ex-ante safety regulations" and "ex-post liability for harm" analyzed by Kolstad, Ulen and Johnson (1990). While this is not the primary purpose of this paper, our analysis may contribute to their conclusions about complementarity and substitutability between the two regulatory measures by providing a case when the use of one measure *limits* the effectiveness

[7] For example, see Segerson (1999) for a discussion of the use of this assumption in food safety models.
[8] Even though an individual food item derived from non-IP ingredients may be correctly labeled as non-GMO, on the average, the non-IP retailers labeling their product as non-GMO are committing a fraud.
[9] Clearly, ex-ante detection of false labeling can be superior to ex-post detection because it is likely that the (expected) harm can be reduced more effectively. For example, suppliers can quickly undertake remediation by recalling or relabeling their supply. Please see Innes (1999) for an insightful exploration of optimal law enforcement when violator remediation is valuable.

of the other.[10]

This article pursues two separate but related issues pertaining to market differentiation between the two food varieties. The first one is the extent of false labeling and a possible role for the government in the voluntary provision of information on GM-content. We show that under certain circumstances, standard means of suppressing an undesirable activity, such as increasing the severity of penalties borne by suppliers, that were caught falsely labeling their product, do not reduce the occurrences of false labeling.[11] An even stronger conclusion is drawn from the analysis of the relationship between segregation costs and the amount of false labeling. In the absence of uncertainty, lower costs of segregation always increase the share of false labels in the "false labeling, partial segregation" equilibrium that will be defined in part one of the paper.

We also demonstrate how instances of false labeling can be made less likely through a government program targeting the level of the segregation between non-GMO and GMO varieties. The case for such a program is particularly strong when there are several shares of non-GMO crop processed separately that may bring the market to equilibrium. However, the conditions for the inefficacy of a harsher penalty and a rebate on the costs of segregation become far less straightforward once uncertainty regarding the economic environment is introduced.

And so the second issue, addressed in part two of the paper, is the effect of uncertainty faced by growers and food processors on equilibrium outcomes. We consider uncertainty stemming from several sources: the volatile demand-side, the hazy government regulations regarding labeling of GM foods, and the unclear segregation costs. An unknown degree of consumer acceptance of the use of biotechnology in food production seems to be an important aspect of the economic environment faced by growers and food manufacturers (e.g., Lin, Chambers, and Harwood (2000) - LCH). Also, concerns that farmers and food

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[10] Other papers discussing the relative benefits of ex-ante and ex-post regulation include Brown (1973), Cooter, Kornhaouser, and Lane (1979), Craswell and Calfee (1986), Shavell (1984) and Shavell (1987).

[11] The point that a higher penalty may increase crime rates is not new. For example, Andreoni (1991) formally demonstrates the possibility that an increase in penalty may actually encourage crime rather than deter it. However, his result relies on the negative relationship between the probability of conviction and penalty and is distinct from ours.

producers have had over a lack of or vagueness in legislation related to biotechnology are well documented (e.g., American Corn Growers Association).

The model developed in this paper captures several important features characteristic of *non-biotech and biotech food* markets. First, substantial investments must be made in the identity preservation (IP) program if a product without any GM ingredients is to be supplied. Second, consumers' preferences between the two varieties are continuously evolving and are not known with certainty when irreversible production decisions are made. Third, the large volume of food production, the variety of sources, and the frequency of food consumption decisions provide a sufficient justification to appeal to the large numbers argument. This becomes important when the probability that a non-GMO label is true or false, as well as the probability that an unlabeled product belongs to a particular variety, are calculated.

In a competitive environment, we consider a two-stage production process where demand uncertainty is resolved only after all production decisions have been made. In the first stage, a fixed stock of land is allocated between biotech and non-biotech varieties. Assuring that a final food product does not contain GMOs involves the practice of separating the conventional crops from their GM counterparts, which is commonly referred to as identity preservation (IP). The decision to invest in the IP procedures is made in the second stage, at which time the crops are sold to the food processing companies (retailers). When demand for non-GMO food variety is high, some firms may find it in their best interest to lie about the origin of their products because false claims are difficult for the consumers to detect.

The rest of the paper is organized as follows. The numbered sub-sections one through four discuss the central features of the model in greater detail. Then a formal model is developed and several policy issues are analyzed. In part one of the paper, we consider the basic model with no uncertainty. The driving force responsible for the non-monotonicity of the price premium paid for a labeled good (which leads to multiplicity of equilibria in the second stage) is highlighted using a simple model with credence goods. In the subsequent sections, a formal model of market differentiation between non-GMO and GMO food varieties and labeling decisions is developed. We start by describing the demand and production environment at harvest and at planting. Then we characterize the equilibrium share of non-IP products falsely labeled as non-GMO when supplies of both varieties are fixed, which is a more general case of the basic setup presented at the outset. After we characterize equilibria at harvest and at planting, we proceed to investigate two policy measures that may be used to combat false labeling. These are raising the penalty (or effectiveness of monitoring) and subsidizing segregation between the two varieties. Result 2 provides precise conditions when these policy measures have an adverse effect, and actually, enlarge the share of falsely labeled supply of non-GMO variety.

In part two of the paper, we introduce uncertainty and demonstrate by means of an example how uncertainty, entering growers' and retailers' decision calculus, may reverse labeling policy implications arrived at in part one. After that, we study the effects of an increase in uncertainty related to demand-side, segregation costs, and/or penalty due to false labeling on the production decisions at harvest and at planting. We conclude with a discussion of our policy recommendations and further possible lines of inquiry.

1. Consumer Preferences and Rational Expectations

Consumer attitudes toward GM foods vary vastly among the population. One important feature of this heterogeneity in preferences is that many consumers will gladly replace GM food with an identical non-GM food. But some consumers are far less willing to have it the other way around. Only if the price of GM product is sufficiently lower than the price of non-GM product will they purchase a product derived using biotech ingredients. Such consumers' behavior has an immediate implication for the equilibrium prices of the two types of food (Lence and Hayes (2000)). Namely, the price of non-GM food will never fall below the price of GM food. The opposite can easily happen though when the demand for non-GM food is sufficiently high compared to the supply.

Of course, consumers cannot detect the GMO content in the foods they buy and have to rely on the information provided by the producer. Assume, for now, that such information is correct. Interestingly, a rational consumer need not assume that an unlabeled product is necessarily of a GM variety. In fact, the probability that a given unlabeled product is non-GM is found as the ratio of the share of non-GM supply net of the share of labeled products over the share of unlabeled products. Hence, on average, a risk-neutral consumer is willing to pay more for an unlabeled product than for a product that is known with certainty to be GM. Additionally, when false labeling takes place a consumer can rationally estimate the probability that a given label is false, and is likely to be willing to pay more for better quality information about the GMO content.

2. Returns to Truthful Labeling

In the jargon of the economics of imperfect information, free markets can generate two distinct outcomes referred to as "separating equilibrium" and "pooling equilibrium." In a separating equilibrium, products are differentiated according to their GMO content. In a pooling equilibrium, products are homogenous with respect to the amount of information accompanying them. Imagine that the supplies of non-GMO and GMO products are fixed and no false labels can be made. To begin with, consider a situation when no products are labeled. Then each product has the same chance of belonging to either variety. As the share of labeled non-GMO products increases, the amount of uncertainty surrounding the remaining supply decreases. As was pointed out previously, GMO-free food is *weakly preferred* relative to otherwise identical biotech food by all consumers (see the sub-section on consumers' preferences above.) As will be clarified shortly, such preferences imply that the prices of both varieties diminish as the supply of labeled non-GMO products grows. Consequently, the relative price of the labeled and unlabeled foods, defined as the difference of the two, can be a non-monotone function of the share of the labeled non-GMO product supply.

On the one hand, the price of the labeled product (weakly) declines (the aggregate demand schedule is downward sloping) as the supply increases. On the other hand, this means that the price of an unlabeled food item (i.e., the food that could be of either type) must (weakly) fall as well because there are fewer chances that this food product is non-GMO. Hence, in general, the difference in prices can either rise or fall when the share of the labeled non-GMO food increases. Running ahead, this will be shown to lead to a potential multiplicity of equilibria in the second stage of the production process when the share of the IP non-GMO products is chosen.

The possibility of making false non-GMO claims and converting the products derived without adhering to the IP procedures into non-GMO market, effectively, puts a cap on the revenues earned by the IP non-GMO food suppliers.

3. Irreversibility of the Segregation or IP Decisions

In the case of agricultural and food manufacturing markets, the decision to supply a non-GMO food product is typically characterized by a certain degree of irreversibility. In the absence of efficient and accessible testing techniques, it can be prohibitively expensive to provide a pure non-GMO product unless the IP procedures have been followed from the beginning. For example, it can be very costly to attempt to segregate commodities into non-GM and GM varieties after the crops have been navigated through the initial stages of the food supply chain. If non-GMO and GMO grains are mingled the cost of truthful labeling tends to escalate quickly. Given the diversity and complexity of food marketing channels, labeling a final product can induce an adjustment to production practices at the early stages of food processing (e.g., see Kalaitzandonakes and Maltsbarger (1998)). Therefore, the decision to supply a pure GMO-free food product needs to be made immediately after non-GMO variety is purchased from the farmer.

For example, LCH present a detailed analysis and some costs estimates of various segregation and IP practices. They distinguish between the two strategies for delivering the non-biotech food product as opposed to undifferentiated food product: "crop segregation" and "identity preservation". According to LCH, IP "requires that strict separation – typically involving containerized shipping – be maintained at all times." While crop segregation, "which requires that crops be kept separate to avoid commingling during loading and unloading, storage, and transportation," puts more pressure on testing for the presence of biotech content, it does not generally involve containerization. For our purposes, such a differentiation is not important and, throughout this paper, we use the terms crop segregation and identity preservation interchangeably. LCH also provide segregation costs estimates based on the study conducted by USDA's Economic Research Service. For example, they conjecture that "rough ballpark figures" reflecting additional costs due to segregation could be \$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.[12]

4. Planting Decisions

At the grower's level, land allocation between the biotech and non-biotech varieties is an irreversible decision made at the time of planting. Farmers receive a positive premium for non-GM crops only in the event that the food manufacturing and retail industries decide to *extensively differentiate* between the two types of food products. Hence, the planting and IP decisions are linked. Demand for the farmers' crops comes from the derived input demands by the retailers. It is only when the demand for non-GM crop exceeds the supply at harvest that a positive premium for non-GM crop emerges. The information about the evolving consumer preferences and production environment available at harvest plays a critical role in the IP decisions. Therefore, it is that information that the farmers will be most interested in when allocating their land between the two crop varieties. However, the fundamental uncertainty faced by the growers at planting and by the retailers at harvest stems from the continuously fluctuating distribution of the consumer preferences.

The model to follow builds on these observations and provides a formal framework to analyze labeling decisions. We will show that, in a two-stage competitive production environment, some standard forms of governmental intervention are not always successful in addressing false labeling. As will be explained, such a failure is caused by the production responses in the stages of segregation and/or planting.

Part 1. False Labeling

Price Premium and Labeling: Basic Feature

The material in this section is meant to illuminate a feature of the economic environment that will play a central role in the analysis of labeling and segregation decisions that follows. Consider a continuum of risk-neutral consumers indexed by $\varepsilon \in \Re_+$ with a continuous

[12] Bullock, Desquilbet and Nitsi (2000) present an alternative set of such estimates.

strictly increasing cumulative distribution function $M(\varepsilon)$, where $M(0)=0$ and $M(\infty)=1$. Let consumer ε's indirect utility be given by:

$$\max[1-p_a, \varepsilon - p_b, 0],$$

where p_a and p_b are prices of goods A and B, and utility derived from consuming a unit of good A is normalized to unity.

Now imagine that goods A and B are credence goods and consumers cannot differentiate between A and B unless they are labeled as such. In a moment, these goods will be identified as non-biotech and biotech food varieties. Also, assume that the total supply of A and B is fixed and equal to 1. The share of product A in the total supply of A and B is given by $a \in [0,1]$. The share of labeled product A is given by $a_L \in [0, a]$. We hold that only product A is being labeled, and all labels are accurate. Then the probability that an unlabeled product, Π, belongs to type A is given by:

$$\Pr(\Pi = A \mid \Pi \in \{Unlabeled\}) = \frac{a-a_L}{1-a_L},$$

i.e., we calculate the probability that a given product A has not been labeled conditional on the share of labeled products A. Then consumer's type ε^* that is indifferent between buying a labeled product A and an unlabeled product is given by:

$$(1) \qquad 1-p_a = \frac{a-a_L}{1-a_L} + \varepsilon^* \frac{1-a}{1-a_L} - p_{un}, \text{ or } \varepsilon^* = 1-(p_a - p_{un})\frac{1-a_L}{1-a},$$

where p_{un} is the price of an unlabeled product.

Hence, in a one-period competitive market, the equilibrium price premium paid for a labeled product A is given by:

$$(2) \qquad M(1-\frac{1-a_L}{1-a}(p_a - p_{un})^*) = a_L,$$

where $(p_a - p_{un})^*$ denotes the equilibrium price premium paid for a labeled product. From equilibrium condition (2) we have:

$$(3) \qquad (p_a - p_{un})^* = (1-a)\frac{1-M^{-1}(a_L)}{1-a_L},$$

where the inverse of $\mathrm{M}(\varepsilon)$, given by $\mathrm{M}^{-1}(.)$, is strictly increasing and exists everywhere owning to the assumptions we made about $\mathrm{M}(\varepsilon)$.

Observe that the RHS of Eqn (3) may not be monotone in the share of the supply of labeled product A, a_L.[13] Briefly, this happens because the equilibrium prices of A and B decline when a_L increases. Observe that the price premium may be increasing in a_L, because the probability that a given unlabeled product is a type B good, $(1-a)/(1-a_L)$, is increasing in the share of the labeled type A products. We will elaborate on this important point several times later on in the paper.

The fact that the price premium paid for the labeled product may be a locally increasing function of the supply of the labeled product is not at all surprising when viewed in the light of the literature on the economics of information. It is well known that in the presence of imperfect or asymmetric information competitive equilibrium may not exist, may not be unique, or may have "strange" properties (e.g., see a seminal paper by Akerlof (1970)).

We employ this model of consumer behavior to gain some insights into the mechanism of market differentiation between non-GM and GM food varieties. In the analysis to follow, we endogenize the supply side of the food market and explicitly model labeling decisions. In addition, we allow for the possibility of making false labels, and, in part two of the paper, we investigate the effects of uncertainty regarding the distribution of preferences among the population, the penalty associated with false labeling, and segregation cost.

Model

There are three time points: 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 labeled.[14] Labeled as type N (possibly falsely so) and unlabeled food

[13] Both the numerator and denominator in the RHS of Eqn (3) are decreasing in a_L.

[14] To focus on the market differentiation between the two varieties, food processing is taken to consist only of preserving (or not preserving) food variety.

items are sold to consumers at time 3. The timing of production and consumption decisions is illustrated in Figure 1.

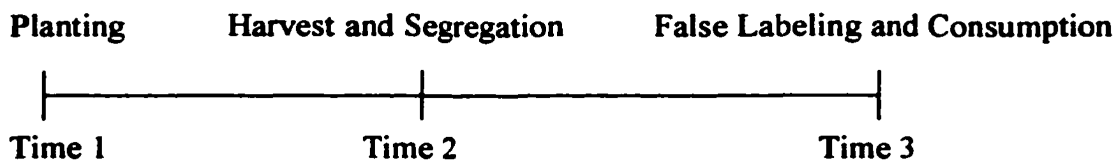

Figure 1. Timing of events

In part one of the paper, we assume that any uncertainty faced by growers arises strictly due to multiplicity of equilibria at harvest. For now, retailers are held to operate in an environment with full certainty except for the inability of non-IP retailers to (costlessly) distinguish between the two varieties.

Demand Side

To spell out the inverse aggregate demand for food varieties, we adapt the specification of consumer preferences considered above. As before, all consumers have unit demands and consume at most one type of (food) products. A type ε consumer's preferences over consumption of one unit of type N food, $t_N = 1$, or a unit of type G food, $t_G = 1$, are given by:

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

That is, any consumer derives unit 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 $\varepsilon \in [0,1]$.[15]

Now the cumulative mass distribution of types has mixed continuous-discrete form with, possibly, strictly positive mass at $\varepsilon = 1$. It is given by $H(\varepsilon, \theta)$ for $\varepsilon \in [0,1)$, and 1 for $\varepsilon = 1$, where function $H(\varepsilon, \theta)$ will be described shortly. In part one of this paper, we hold

[15] Observe that this means that all consumers *weakly prefer* type N food. In terms of the previous section, we restrict ε to be in a unit interval and we require that $M(1) = 1$.

the distribution conditioning parameter $\theta \in [0,1]$ to be fixed.[16] We assume that $H(1,\theta) \le 1$, and function $H(\varepsilon,\theta)$ is defined on $\varepsilon \in [0,\varepsilon^+(\theta)]$, where $H(0,\theta) = 0 \ \ \forall \theta \in [0,1]$ and $\varepsilon^+(\theta) = \inf_z\{z : H(\varepsilon,\theta) = 1\}$. The mass of indifferent consumers is then given by $1 - H(1,\theta)$. We hold that $H(\varepsilon,\theta)$ is strictly increasing and continuous in ε on $\varepsilon \in [0,\varepsilon^+(\theta)]$. Then an inverse of $H(\varepsilon,\theta) = z$ always exists $\forall \ z \in [0,1]$ and is given by $\varepsilon = J(z,\theta)$. We also assume that $J_\theta(z,\theta) \ge 0 \ \ \forall z \in [0,1], \ \forall \theta \in [0,1]$ so that an increase in θ (weakly) shifts the preferences towards type G food. Given that each consumer consumes at most one unit of a food product, an increase in θ can be alternatively stated as a shift of the preferences away from type N food.

The consumers cannot differentiate between type N and G food products unless they are labeled as such. However, we assume that the consumers rationally anticipate that a label can be false. Then type ε consumer's gross utility derived from consuming a labeled good is given by:

$$1 \cdot \Pr(t_N \mid \text{Labeled as non-GMO}) + \varepsilon \cdot \Pr(t_G \mid \text{Labeled as non-GMO}).$$

If a product is not labeled, the consumers do not know whether the food is of type N, or of type G. A type ε consumer that considers purchasing an unlabeled product rationally estimates his utility of consumption as:

$$1 \cdot \Pr(t_N \mid \text{Unlabeled}) + \varepsilon \cdot \Pr(t_G \mid \text{Unlabeled}).$$

Furthermore, consumer's utility is quasi-linear in a numeraire good, and the consumers always have the option of staying out of the food market.

Supply Side

At time point 1, the 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, $y = 1$, is constant and invariant across varieties. Unit production costs of varieties N and G are given by c_N and c_G, where

[16] In what follows, we will often suppress argument θ in functions $H(\varepsilon,\theta)$ and $J(z,\theta)$. However, demand shifter, θ, will play a vital role in the analysis of uncertainty in part two of the paper, where θ will be modeled as a random variable realized at time 3.

$1 > c_N > c_G > 0$. The amount 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 $(1-x)$.

The possibility of a "contaminated" non-biotech or biotech variety due to cross-pollination between GM and non-GM varieties is assumed away. 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.[17] This implies that the non-IP suppliers do not differentiate between the two crop varieties and always purchase the cheaper one.

Both the raw crop and food retail markets are competitive. At time point 2, after the harvest, homogenous and risk-neutral 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 N and G, respectively.[18] Then some retailers decide to supply the IP type N food while others choose not to invest in the IP program. The IP food suppliers segregate and process separately a share of variety N crop denoted by $S \in [0, x]$. The unit cost of following the identity preservation procedures is given by $c_S \in [0, 1-c_N)$.[19] Here, we assume that the production practice of identity preservation necessarily involves handling varieties N and G separately. The cost of doing this at time 3 is prohibitively high. Therefore, those retailers who do not invest in the IP program do not know with certainty the kind of crop they process and, hence, the GMO content of their final food products.

False Labeling and Penalty

At time point 3, some retailers may decide to cheat and market a non-IP product as type N food. Both a non-biotech identity-preserved (IP) product and an uncertified product can be

[17] To focus on the information asymmetry at the consumer's level, we 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 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.

[18] The assumption of risk-neutrality will become relevant when we introduce uncertainty in Part 2.

[19] If $c_S + c_N \geq 1$ then, trivially, no variety N is planted because consumer's value of type N food is normalized to 1 (and it is common to all consumers), and consumers always have the option to stay out of the food market.

labeled as variety N at no cost. The consumers have no way of telling a true label from a false one without a costly verification procedure. 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 GMO content under non-GMO label (see Figure 2).

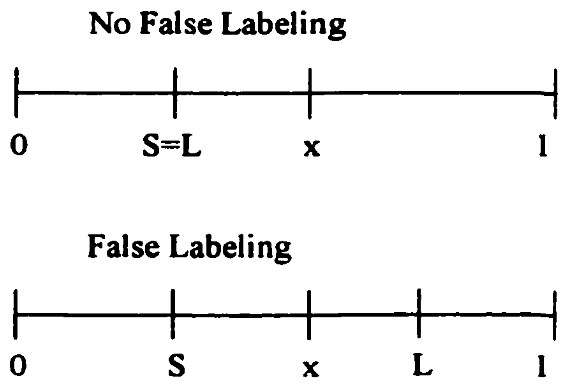

Figure 2.

Note that the share of the "ex-ante" false labels is given by:

(4) $1 - q_a(S,L)$,

where $q_a(S,L) \equiv S/L$ is the share of labeled products that were processed following the IP practices. The share of the "ex-post" false labels is given by:

(5) $[1 - q_a(S,L)] \cdot q_b(x,S)$,

where $q_b(x,S) \equiv (1-x)/(1-S)$ is the probability that a non-IP food item belongs to variety G. Throughout this paper, when we use the term "false labeling" without a modifier, we refer to both the "ex-ante" and "ex-post" false labeling unless specified otherwise. Clearly, if a label is detected to be false "ex-post" than it must be false according to the "ex-ante" definition as well.[20] However, throughout this paper, we assume that only "ex-post" false labeling is penalized.[21]

In actuality, both types of false labels are discovered over a period of time during which food products are continuously consumed. Hypothetically, false claims can be

[20] As was mentioned before, we assume away any mixing of the two varieties if variety N is processed following the IP procedures.
[21] As will be demonstrated, the flavor of the results derived in this paper is largely invariant to the choice between the "ex-ante" and the "ex-post" penalty.

detected before, during, or after the food items in question have been purchased. Therefore, in some food markets it seems probable that consumers may engage in strategic behavior and wait until they have access to more information about particular food products. However, in other food markets, it may be impractical to postpone purchases, say, due to the unavailability of an attractive alternative food, excessive search costs, difficulty in switching brands, etc. In addition, the amount of time it takes to attain trustworthy information about a food item may render the option to wait infeasible (or too costly) from a practical point of view.

In this paper, we hypothesize that food consumption takes place instantly and that false labels are recognized after the food has been consumed. This implies that a falsely labeled supply is not converted into a market for unlabeled food items. Therefore, this model is more descriptive of food markets where storage is problematic, and consumption cannot occur with sustained time lapses. In general, we could add an intermediate production stage that takes place after food is segregated and processed but before final food products are consumed. In this intermediate stage, prescreening of food labels may transpire, and the food items that did not meet the claims made about them may then be sold (possibly relabeled) in a different market. This model explores a special case where such prescreening is completely ineffective (or is too lengthy to implement) and consumers cannot delay food consumption to learn more about the accuracy of food labels.

At time 3, after fraudulent labeling has (or has not) taken place, the equilibrium prices of the labeled product, p_L, and unlabeled product, p, are established.[22] If discovered, false labeling is subject to a penalty, F, and legal liability. For concreteness, we hold that only food items labeled as variety N but *actually* belonging to variety G can be spotted.[23] We

[22] In part two of the paper, where parameter θ, governing the distribution of preferences, is random, it is assumed that θ is realized at the very beginning of time 3 before any marketing decisions have been made.

[23] We also hold 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: fail 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)).

further assume that the government or consumer groups have a success rate $\alpha \in [0,1]$[24] of discovering such cases of cheating. Then the probability that a retailer will be caught is calculated as $\alpha q_b(x,S)$, and the expected penalty is given by:

$$\Pr(\text{Fraud is Detected} \mid \text{non - IP retailer}) \cdot F = q_b(x,S)\overline{F},$$

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

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

An extensive-form game for the market differentiation between varieties N and G is shown in Figure 3. In Figure 3, the last five rows of the market differentiation game tree are the payoffs to the producers that will be shortly discussed in detail. Observe that variety N growers (there are x such growers) get a profit of $f_N - c_N$ per acre only if IP retailers choose to buy *all* of the variety. Otherwise, the price of variety N gets bid down to f_G since non-IP retailers do not differentiate between the two varieties and will not pay the price premium. To analyze this game, we 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.

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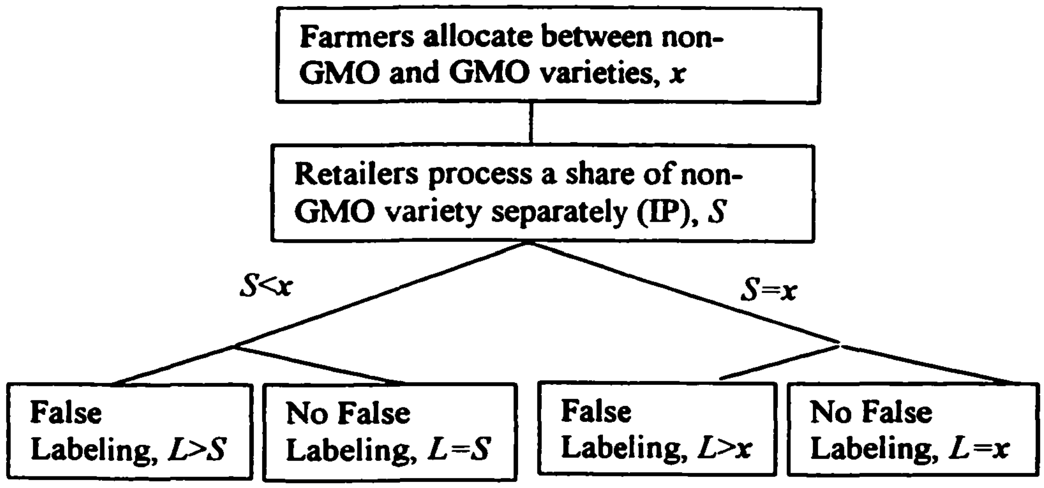
[24] Parameter α can be thought of as the probability of detecting a (ex-post) false label by the monitoring agency when the label is false (ex-post). The probability of detection is an important policy variable but it is taken to be exogenous during most of the analysis. One could hypothesize that the optimal monitoring effort can be a function of the share of ex-ante false labels. We will not complicate the model 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).



	False Labeling, $L>S$	No False Labeling, $L=S$	False Labeling, $L>x$	No False Labeling, $L=x$
N grower :	$f_G - c_N$	$f_G - c_N$	$f_N - c_N$	$f_N - c_N$
G grower :	$f_G - c_G$	$f_G - c_G$	$f_G - c_G$	$f_G - c_G$
IP retailer :	$p_L - f_G - c_S$	$p_L - f_G - c_S$	$p_L - f_N - c_S$	$p_L - f_N - c_S$
non - IP retailer :	$p - f_G$	$p - f_G$	$p - f_G$	$p - f_G$
false/non - IP :	$p_L - f_G - q_b\overline{F}$	-	$p_L - f_G - q_b\overline{F}$	-

Figure 3. Three stage game of market differentiation

It will be shown that, in general, competitive market at harvest time 2 may support *several* shares of segregation between the two varieties. Therefore, at planting time 1 the level of segregation is viewed as an *endogenously* arising random variable realized at time 2. Variety N growers will be particularly concerned with the probability of the event that $S = x$ since only in that case variety N will fetch a higher price. As we will see, the equilibrium probability distribution of S (and hence, L) is, typically, not unique. We proceed by characterizing the market equilibrium conditions at time 3, time 2, and time 1 in the *absence* of uncertainty. Then we turn to analyzing the effects of raising fines for false labeling and subsidizing segregation costs on the equilibrium share of falsely labeled supply of type N food products. Exploring the effects of *uncertainty* on the nature of equilibrium is deferred to part two of the paper.

Retail Market at Time 3

At the end of time 3, the share of variety N crop, x, the share of the IP product, S, and the share of labeled product, L, are fixed. We assume that all consumers make their decisions based on the common information set.

In general, there are two ways in which a non-GMO labeled food product can turn out to be type N. It can be either "IP" from the beginning and then there is $q_a(S,L)$ chance that the label is not false. 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 that is equal to $[1-q_a(S,L)]\cdot[1-q_b(x,S)]$. The last expression implies that two events happen. First, the label is false. Second, given that the label is a fraud, it so happened 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:

$$q_a(S,L)+[1-q_a(S,L)]\cdot[1-q_b(x,S)].$$

As was indicated previously (see (5)), the probability that a labeled product is a type G food is given by $[1-q_a(S,L)]\cdot q_b(x,S)$. This expression has a similar interpretation. The probability that an unlabeled product is, in fact, of type N is given by $1-q_b(x,S)$. The only piece of information conveyed by the absence of a label is the fact that the product is, certainly, non-IP. On the other hand, there is probability $q_b(x,S)$ that the unlabeled product is of type G.

Then, a type ε consumer utility at time 3 is given by:

(6) $$\max[\{q_a+(1-q_a)(1-q_b)\}\cdot 1+(1-q_a)q_b\cdot\varepsilon-p_L,\ (1-q_b)\cdot 1+q_b\cdot\varepsilon-p].$$

In the manner of Eqn (1), the threshold type ε^* that is indifferent between purchasing a unit of the labeled and unlabeled product can be found as:

(7) $$\varepsilon^*=1-[p_L-p]/[q_a q_b].$$

Equilibrium in the retail market is then given by:

(8) $H(\varepsilon^*)=L$, if $\varepsilon^*<1$ and $\varepsilon^*=1$, if $H(1)\le L$.

If the supply of non-GMO labeled food is "low" ($H(1)>L$), then some consumers are willing to pay a positive premium for the labeled product. When the supply is "high"

($H(1) \leq L$), the prices of non-GMO and unlabeled products equate. Substitute (7) into (8) and take the inverse to obtain:

(9a) $p_L^* - p^* = q_a(S,L)q_b(x,S)(1 - J(L,\theta))$, if $J(L) < 1$;

(9b) $p_L^* - p^* = 0$, if $J(L) \geq 1$;

where the superscripted "*" denotes the equilibrium values.

Rewrite Eqn (9) in the following form:

(10) $p_L^* - p^* = q_a(S,L)q_b(x,S)\max[1 - J(L),0]$.

Observe that Eqn (3) is a particular case of Eqn (10) with $L \equiv S \;\; \forall S$, i.e., when no false labeling occurs and $J(1,\theta) = 1$, i.e., when the mass of indifferent consumers is equal to zero. Until part two of the paper and without loss of generality, we will hold that $H(1,\theta) = 1$, and hence, $J(1,\theta) = 1$ for all θ.

Equilibrium False Labeling

If demand for type N food is high (i.e., θ is low), the retailers who did not invest in the segregation and did not follow the IP program may decide to engage in false labeling. The expected (average) profit from such an activity is given by:

(11) $p_L - q_b(x,S)\overline{F}$.

The equilibrium amount of the labeled product is then given by:

(12a) $p_L^* - q_b(x,S)\overline{F} = p^*$, if $L^* > S$;

(12b) $p_L^* - q_b(x,S)\overline{F} < p^*$, if $L^* = S$.

Substituting Eqn (10) in (12) we obtain the following equilibrium conditions:

(13a) $p_L^* - p^* = q_b(x,S)\overline{F}$, and $q_a(S,L^*)(1 - J(L^*)) = \overline{F}$, if $L^* > S$;

(13b) $p_L^* - p^* = q_b(x,S)(1 - J(S))$, if $L^* = S$,

where we take that $\overline{F} \leq 1$ because otherwise Eqn (13a) will never hold and the prospect of getting caught and fined completely eliminates any fraudulent labeling. Summarizing, we can rewrite Eqn (13) as follows:

(14) $p_L^* - p^* = q_b(x,S)\min[1 - J(S), \overline{F}]$.

At this point, we draw the reader's attention to an important feature of Eqn (14). Observe that the RHS of (14) is non-monotone in S unless further assumptions on the curvature of $J(L)$ are made. From Eqn (7), in equilibrium the threshold type is given by $\varepsilon^{*} = J(S)$. Then the difference between the equilibrium prices, when no false labeling takes place, is equal to the share of types that purchase the unlabeled product weighted by the probability that the unlabeled product is of type G. As S increases both the probability that the unlabeled product is of type G and the threshold type increase. Hence, the combined effect on the RHS of (14) is ambiguous.

Now we turn back to analyzing the retailers' behavior at time 3. Consider some implications of the time 3 equilibrium condition as stated in Eqn (14). First, observe that an increase in the consumers' "confidence" in labeling, S, will decrease the probability of fraud, $\Pr\{1 - J(S^{*}) \geq \overline{F}\}$.[25] When the true share of the IP products, S, increases the aggregate demand for labeled food items falls. Then the non-IP retailers have less incentive to convert their supply into the labeled non-GMO food market. It would seem that a higher value of S also contributes to diminishing fraud through its effect on the likelihood of being caught cheating, $\alpha q_{b}(x, S)$. However, this is not the case. As pointed out above, the effect of an increase in S on the price premium paid for non-GMO labeled food, $p_{L}^{*} - p^{*}$, can be decomposed into two effects. From Eqn (13a) or Eqn (14), it is clear the effect of a higher S on the probability that a non-IP product belongs to variety G is cancelled out.

Also, observe that the condition that needs to be satisfied when false labeling takes place, $1 - J(S) \geq \overline{F}$, depends only on S and $\overline{F}$. The value of x reveals its impact indirectly through $S^{*} = S(x, c_{S}, \overline{F})$, which is established after x is fixed at planting (see the sub-sections to follow). The attribute of relevance when studying the relationship between the extent of segregation and the ex-ante false labeling is the share of "ex-ante" false labels in

[25] See the preceding discussion of two different ways to define false labeling. In this paper, a label is false if the information conveyed by the label *may* not be accurate which happens when a non-IP processed product is labeled as type N variety.

percentage terms, $1-q_a(S,L^*)$ (see (4)).[26] Analyzing Eqn (13), we obtain a useful finding.[27]

LEMMA 1. The equilibrium share of falsely labeled supply at time 3 decreases when the level of segregation increases.

The fact that the share of "ex-ante" false labels is always decreasing in the level of segregation will allow us to formulate relatively sharp results concerning the effects of a higher penalty or lower segregation costs. In the manner of lemma 1, it can be shown that a higher level of segregation has an ambiguous effect on the share of the "ex-post" false labels as defined in (5). Therefore, in general, policy recommendations implied by the programs oriented to minimize "ex-ante" and "ex-post" false labeling using "policy" variables such as $\overline{F}$ and c_S need not coincide.[28]

In addition, note how the possibility of false labeling limits the potential premium to be paid for the non-GMO IP food products. From (13a) it is immediate that a higher value of $\overline{F}$ will always *lower* the share of false labels *for a given* S. Summarizing, there are two complementary means available to combat false labeling at time 3. Raising either $\overline{F}$ or S will decrease the revenues accrued to suppliers falsely labeling a final food product.[29] However, we shall see that, under certain conditions, the former tool may be ineffectual. Namely, when S and x are endogenously determined within the model, an increase in $\overline{F}$, *anticipated* by agricultural producers, may lead to a lower equilibrium value of S at time 2, and therefore, may actually *increase* the share of false labels at time 3. In general, we have the following result.

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[26] To detect this sort of false claims (referred in the text as "ex-ante false labeling") one can verify adherence to the IP production practices at various stages of food processing.

[27] All the proofs not provided in the text are contained in Appendix A.

[28] The objective to minimize the share of non-IP supply labeled as variety N that, in fact, belongs to variety G, $(1-S/L^*)\cdot(1-x)/(1-S)$, over S is clearly different from minimizing the share of non-IP supply that labeled as variety N, $(1-S/L^*)$, over S.

[29] In the model, S is fixed after time 2, i.e., it is taken to be prohibitively costly to affect the level of segregation at time 3.

LEMMA 2. The equilibrium share of falsely labeled supply at time 3 can either increase or decrease depending on whether $\partial S(\overline{F})/\partial\overline{F} < (\geq)(-1)/J_L(L^*)$.

Lemma 2 states that the equilibrium share of falsely labeled supply at time 3 will increase as a result of a higher expected penalty if the level of segregation responds negatively and such a response is sufficiently strong. An increase in $\overline{F}$ has two effects on the share of false labels, $1-q_a(S(\overline{F}),L^*)$. As was mentioned previously, the direct effect is operative at *time 3*, and it unambiguously (weakly) lowers L^*. The indirect effect works its way through a change (either positive or negative) in the level of segregation *at time 2*, S.[30] If S responds relatively more (in absolute terms) to a small increase in $\overline{F}$ than the inverse aggregate demand, $J(L^*)$ to a small increase in L^* for a given θ, then the negative indirect effect dominates and the share of false labeling will rise at time 3. If the equilibrium level of segregation rises at time 2 when $\overline{F}$ increases, then the share of false labels must always fall at time 3. To provide further characterization of the relationship between the penalty and the amount of fraud, we need to understand how the level of segregation is determined. And so, we now turn to describing the behavior of the retailers facing the price differential given by Eqn (14) at the harvest time 2.

Raw Crop Market and Segregation at Time 2

At time 2, the competitive retailers equate the net revenues from selling the IP (labeled) and non-IP (labeled or unlabeled) products. If a retailer decides to supply the IP product, she buys variety N and incurs the IP cost. She knows that at time 3 her product will fetch a price weakly larger than the price of an unlabeled product. Hence, the per unit profit from selling the IP (labeled) product is given by:

(15) $\max[p_L, p] - c_S - f_N$.

The per unit profit from selling a non-IP product is given by:

(16) $\max[p, p_L - q_b\overline{F}] - \min[f_G, f_N]$,

[30] The level of segregation will also be affected by the acreage allocation because such an announcement (that $\overline{F}$ will be raised) may affect growers' calculations. We will say more on this point in what follows.

where the min[.,.] statement signifies that the provider of an unlabeled product does not care whether he uses variety N or G as a raw input,[31] and max[.,.] implies that a retailer always has the option to falsely label her final food product.

Observe that we can write the difference between the revenues from selling a truly type N food and from selling an unlabeled product (with the option of fraudulent labeling) gross of the production cost in the following form:

(17) $\max[p_L, p] - \max[p, p_L - q_b\bar{F}] = \min[\max[p_L - p, 0], q_b\bar{F}]$.

Equating the profit earned by IP retailers, (15), with that accrued to non-IP retailers, (16), using the gross revenue differential, (17), and substituting time 3 equilibrium price premium, (14), we obtain the following condition describing the market equilibrium at time 2:

(18) $q_b(x, S^*)\min[1 - J(S^*), \bar{F}] = c_S + \max[f_N^* - f_G^*, 0]$.

At time 2, the share of variety N processed in isolation from variety G adjusts until the profit from IP processing are equated to the profit from supplying products with an unknown GM content.

In general, models of imperfect or asymmetric information are notorious for having "strange" or multiple equilibria.[32] We have already discussed an interesting aspect of the LHS of Eqn (18) – its non-monotonicity in S^*. As was highlighted in the discussion that followed Eqn (14), the price premium paid for type N food is composed of two terms so that a small increase in S^* has, in general, an ambiguous effect. On the one hand, the probability that a non-IP product belongs to variety G 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. As the share of the IP product rises, the supply of non-IP products becomes less valuable because a given non-IP product is less likely to be type N. This drives the price fetched by an unlabeled non-IP product down. However, the price of the labeled product (weakly) declines as well simply because there are fewer people willing to pay a premium for

[31] As was elaborated upon above, the retailers gain nothing from buying N rather than G variety unless the IP investment has been made. In other words, the non-IP retailers take the probability of being caught cheating (falsely labeling a product) as given.

[32] For example, please see a seminal paper on competitive insurance markets by Rotschild and Stiglitz (1976))

type N food as the demand for it is becoming sated.

Inspecting (15), (16), and (18), along with the fact that the farmers competitively supply fixed quantities of crops N and G, we conclude the following. First, $f_N^* < f_G^*$ is impossible in equilibrium since then there will be an excess supply of variety G crop. We also know that if $S^* < x$ then we must have $f_N^* = f_G^*$. Otherwise, there will be an excess supply of variety N crop. Also, if we have $S^* = x$ in equilibrium at time 2 then it must be that $f_N^* \geq f_G^*$.

In general, we cannot guarantee that for each x there exist $S^* \in (0, x)$ and $f_N^* - f_G^*$ such that Eqn (18) holds with equality. First, we consider the conditions under which the outcomes with $S^* = 0$ and $S^* = x$ emerge. The LHS of Eqn (18) evaluated at $S^* = 0$ reduces to $(1-x)\overline{F}$ because of our assumptions about $\overline{F}$ and $J(0) = 0$.[33] In the equilibrium where the retailers decide not to segregate at all, the expected price premium for the IP product (evaluated at $S^* = 0$) is less than the cost of segregation, and this is characterized by the condition:

(19) $(1-x)\overline{F} \leq c_S$.

In words, the share of variety N in total supply is too high and the penalty is too low to render the costly investment in the segregation a viable business decision.[34] Alternatively, if too much of variety N has been planted, or if the penalty from cheating is low compared to the segregation cost then no segregation will take place.

On the other hand, if all of variety N is processed according to the IP program then we must have:

(20) $\min[\max[1 - J(x), 0], \overline{F}] \geq c_S$.

In this case, the expected price premium to be paid for type N food products is higher than the segregation costs. Consider a special case when the share of variety N, x, is low and we

[33] We remind the reader that we postulate that $H(0,\theta) = 0 \; \forall \theta \in [0,1]$.

[34] Note that condition (16) does not depend on uncertainty surrounding θ (uncertainty will be investigated in part two of the paper). This is the consequence of taking the measure of consumers who are strictly averse to type G food (i.e., those with $\varepsilon = 0$) to be zero. One can imagine considering the distribution of types with two, possibly, strictly positive mass points at $\varepsilon = 0$ and $\varepsilon = 1$. This would slightly complicate the analysis without providing new insights.

have $1 - J(x) \geq \bar{F}$. Then condition (14) reduces to $\bar{F} \geq c_S$. In this special case, the equilibrium set includes both $S^* = 0$ and $S^* = x$ when $(1-x)\bar{F} \leq c_S \leq \bar{F}$.

Summarizing, we rewrite equilibrium equation (18) as it pertains to the "no segregation", the "partial segregation", and the "full segregation" equilibria:[35]

(21a) $(1-x)\bar{F} \leq c_S$, when $S^* = 0$;

(21b) $q_b(x, S^*)\min[1 - J(S^*), \bar{F}] = c_S$, when $S^* \in (0, x)$;

(21c) $\min[1 - J(x), \bar{F}] = c_S + f_N^* - f_G^*$, when $S^* = x$.

Observe from Eqn (21) that when $c_S \geq \bar{F}$, the "no segregation" equilibrium, $S^* = 0$, is the only possible equilibrium. So from now on it is assumed that $c_S < \bar{F}$. As another special, but important, case we consider what happens when $c_S = 0$. Then condition (19) always holds, and we have $S^* = x$, and variety N is sold at a premium. The outcome that all of the premium variety is segregated is very intuitive since the segregation can be done at no cost. The strictly positive premium for N crop is the consequence of the consumers' weak preference toward type N food. It is worth pointing out that this is the only possible equilibrium when the segregation is cost-free. Recapitulating, we have:

RESULT 1.[36] a) If (19) and (20) hold simultaneously then the set of possible equilibrium outcomes at time 2 includes both the "no segregation" equilibrium, $S^* = 0$, and the "full segregation" equilibrium, $S^* = x$;

b) If $c_S \geq \bar{F}$ then the "no segregation" equilibrium, $S^* = 0$, at time 2 is unique;

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[35] Note that the "no segregation" equilibrium corresponds to pooling equilibrium and the "partial" and the "full segregation" equilibrium correspond to separating equilibrium in the terminology of models of imperfect information.

[36] One could see a certain parallel between costly signaling in the celebrated labor market model (Spence (1974)) and labeling decisions. Here labeling (a signal sent to consumers) *may be* costlier to non-IP retailers than IP retailers at time 3 if the penalty for false labeling is large. This is a necessary condition (part b of the result) for "signaling" equilibrium to exist. Similarly, if it costs nothing to be able to send a cheaper signal (i.e., to reduce the probability of being penalized at time 3) then the level of segregation will be maximal (part c of the result). Using Spence's terminology, in our approach, the distribution of signaling costs (expected penalty for false labeling) and abilities (supply of variety N or G) among workers (retailers) is determined *endogenously* at time 2.

c) If $c_S = 0$ then the "full segregation" equilibrium, $S^* = x$, at time 2 is unique.

Running ahead, note that the wording of result 1 remains unchanged when there is uncertainty regarding the value of θ and retailers calculate the expectation of the price premium for (labeled) variety N paid at time 3 (see part two of the paper where uncertainty is introduced).

It is instructive to rewrite conditions for the "partial" and "full" segregation equilibria, Eqn (21b) and (21c), in a more detailed form as follows:

(22b) $\begin{cases} q_b(x,S^*)(1-J(S^*)) = c_S,\ 1-J(S^*) \le \overline{F} \\ q_b(x,S^*)\overline{F} = c_S,\ 1-J(S^*) > \overline{F} \end{cases}$, when $S^* \in (0,x)$;

(22c) $\begin{cases} 1-J(x) = c_S + f_N^* - f_G^*,\ 1-J(x) \le \overline{F}, \\ \overline{F} = c_S + f_N^* - f_G^*,\ 1-J(x) > \overline{F} \end{cases}$, when $S^* = x$.

False labeling is somewhat more likely to occur in the "partial segregation" equilibrium, $S^* \in (0,x)$, given by the second line in Eqn (22b).[37] We will refer to such an equilibrium as the "false labeling, partial segregation" equilibrium. Note that condition $1-J(S^*) > \overline{F}$ can be rewritten in terms of the distribution of preferences among consumers, $H(\varepsilon)$:

(23) $S^* < H(1-\overline{F})$.

Condition (23) says that the share of consumers who are averse to variety G (i.e., those with $\varepsilon \le 1-\overline{F}$) must be sufficiently large. If (23) holds, then

(24) $S^* = 1-\overline{F}(1-x)/c_S \in (0,x)$

is a possible "partial segregation" equilibrium outcome. In this case, the level of segregation does not depend on the form of the inverse demand function, $J(.)$. Observe from (24) that equilibrium S^* varies inversely with $\overline{F}$ but it increases in c_S and x. At first, such relationships between the level of segregation and economic environment may seem counterintuitive. An intuitive explanation of the relationships between S^* and $\overline{F}$, and S^*

[37] We are intentionally vague in this statement because the equilibrium value of x is often indeterminate. In general, only an upper bound on the equilibrium value of x can be established (please see the section on planting time equilibrium).

and c_S as well as their implications for labeling policy are the subject of the next section.

Effects of an Increase in Penalty and Segregation Costs when Supply at Harvest is Fixed

In this section, we derive one of the key results of this paper. In the absence of uncertainty regarding aggregate demand and policy variables, we find rather general conditions on the economic environment such that a harsher penalty for false labeling (credibly announced at time 2)[38] or lower segregation costs will, in fact, *increase* the equilibrium share of falsely labeled variety N.

RESULT 2. Assume that (i) $1 - J(1-(1-x)\overline{F}/c_S) \geq \overline{F}$ and that the "partial segregation" equilibrium, $S^* = 1 - \overline{F}(1-x)/c_S \in (0, x)$, prevails at time 2, and (ii) the share of variety N supplied at harvest, x, is taken as given. Then we have the following:

a) the equilibrium share of false labels increases when the expected penalty, $\overline{F}$, increases if $J_L(L^*) \geq c_S/(1-x)$, where L^* is given by Eqn (7a);

b) the equilibrium share of false labels decreases when the segregation costs, c_S, increases.

Result 2 provides an interesting insight and important policy implications. Observe from (22b) that condition $1 - J(1-(1-x)\overline{F}/c_S) \geq \overline{F}$ states that the price premium that would have been paid for variety N, if there were no false labeling, exceeds the penalty associated with dishonest retail practices. In such a case, the price premium for variety N is given by $q_b(x, S^*)\overline{F}$ because non-IP retailers label some of their supply as variety N, and sell their labeled products along with those supplied by IP retailers. As was highlighted previously, the price premium is the product of the expected (average) penalty, $\overline{F}$, and the probability that a given non-IP product belongs to variety G, $q_b(x, S^*)$. Then time 2 equilibrium is asserted when this premium is equal to the segregation costs incurred by the IP

[38] Here we hold x fixed. This is a reasonable assumption if at time 1 growers do not anticipate a change in $\overline{F}$ and c_S.

retailers (see the second line in (22b)). If the penalty increases, then the probability, $q_b(x, S^*)$, must fall to reassert the equilibrium.

It is somewhat easier to see the rationale behind such a response if the level of $\overline{F}$ is lowered rather than raised. Then non-IP processing and cheating at time 3 appears more attractive. To bring down the incentive to exert dishonest behavior, the IP retailers can be thought of as bumping up the probability that a falsely labeled product will be detected by raising the level of segregation at time 2. Such "odd" behavior becomes more transparent once $q_b(x, S^*)\overline{F}$ is interpreted as the (average) "cost" imposed on non-IP retailers who falsely label their products at time 3 (please see footnote 36).

When equilibrium S^* falls, the two effects of an increase in $\overline{F}$ on the share of falsely labeled variety N, $1 - q_a(S^*, L^*)$, compete with each other (please see the discussion following lemma 2). The indirect effect, working though a decrease in S^* at time 2, dominates, if the inverse demand schedule is sufficiently responsive to a small increase in the share of labeled products, L^* (namely, if $J_L(L^*) \geq c_S/(1-x)$). Then the ratio $1 - q_a(S^*, L^*) = 1 - S^*/L^*$ increases.

Part (b) of the result appears to overturn the "standard" economic intuition as well. When the costs of segregation increase, the share of falsely labeled supply is affected only though the change in S^*. When the level of c_S increases, the level of S^* must rise also (see the second line in (22b)). Given that some labels are false, the optimal response by retailers is to increase the level of segregation so that the price premium received by the IP retailers is high enough to compensate for higher segregation costs.

Result 2 has an important policy implication.[39] Namely, when a policy goal is to reduce the probability of false labeling taking place, the conventional measures targeting

[39] A note is in order that Result 2 is only local in the following sense. If the expected penalty is lowered or the segregation costs are raised until we have $c_S \geq \overline{F}$, then no segregation occurs and consequently, the problem of false labeling disappears. However, such an outcome may not be socially desirable. We do not seek the optimal penalty and monitoring effort (in the manner of the literature on optimal regulation) partly because, as we will see, the equilibrium share of acres sown to variety N is, in general, indeterminate which causes difficulties for the analysis of the optimal policy.

$k = c_S, \overline{F}$ may have an adverse effect.[40] To increase the likelihood of the success of such programs some efforts to boost the popularity of the segregation practices can be helpful when the adverse effect is caused by an increasing expected premium paid for non-GMO labeled food products. If multiple equilibria at time 2 are admissible, the government may try to force the market to move to the equilibrium with a higher S^*. In particular, an equilibrium with a higher level of segregation always exist when the expected premium is locally increasing in S.[41] Then, for example, some stewardship programs targeting the IP practices can be used to achieve the objective of forcing the market to a higher level of segregation.

Before proceeding further with the development of the model, we take a bit of a digression. We investigate the consequences of pairing the "ex-ante" goal with the "ex-post" penalty. 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 our 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 have the authority to penalize not only the "ex-post" false labeling but also the "ex-ante" false labeling. We remind the reader that the latter type of false labeling occurs when non-IP retailers label their supply as variety N. It is held that the "ex-ante" inspection activities take place at time 3.[42] The amount of the fine charged to a non-IP retailer who is detected falsely labeling his

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[40] Here we are not concerned with the actual GM-content of a food item. The focus is on the fact that a non-IP processed product is labeled as non-GMO.

[41] In addition, all equilibria with the price premiums increasing in S are unstable (please see Example 1 below for details on this point).

[42] This, of course, raises the question of what happens to the exposed "ex-ante" falsely labeled supply. As was mentioned previously (see subsection "False Labeling and Penalty"), realistically, the non-IP retailers that were caught cheating can convert their products into variety G (or unlabeled) market. We choose not to complicate the analysis by extending the model in this direction. In addition, an alternative timing of the two types of inspection can be considered (for example, the inspection detecting the "ex-ante" false labels is likely to precede detecting the "ex-post" false labels.)

supply (in the "ex-ante" sense) is denoted by F_a. We assume that the share of non-IP retailers who are spotted labeling their products as variety N is given by $\beta \in [0,1]$.[43] Furthermore, we hold that retailers are subjected to both types of inspection: "ex-ante" and "ex-post". Retailers are taken to pay a larger of the two fines if both inspections were successful in detecting the fraud. Then the combined expected (or average) 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 a 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, $1 - q_a(S, L^*)$, can either rise or fall when the level of segregation, S, increases depending on whether

(25) $(1-x)J_L(L^*) < (\geq)\ \beta F_a$,

where L^* is determined by (see Eqn (14a)):

$$q_a(S, L^*)q_b(x,S)(1 - J(L^*, \theta)) = \alpha q_b(x,S)(F - \beta F_a) + \beta F_a.$$

Hence, part (b) of Result 2 needs to be modified to accommodate the new condition (25). Similarly, conditions in part (a) are modified when the "ex-ante" inspection of the labeled supply at time 3 replaces the "ex-post" monitoring. 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. We merely point out 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.

In the following sub-section, we present examples when increasing the severity of the penalty for false labeling or subsidizing segregation costs leads to a larger share of false labels in the "false labeling, partial segregation" equilibrium.

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[43] A discussion similar to that in footnote 24 applies to parameter β as well.

Multiple Equilibria at Time 2 and Some Policy Analysis: Examples

First, we consider an example with a uniform distribution of preferences among consumers while allowing for a strictly positive mass of indifferent consumers with $\varepsilon = 1$. Here, the multiplicity of equilibria is driven by non-linearity arising due to the upper bound on the price premium for variety N, which is brought about by retailers who falsely label their products at time 3.

EXAMPLE 1, Part (a). Let $H(\varepsilon,\theta) = \begin{cases} 0, \varepsilon \in [0,\theta) \\ \varepsilon - \theta, \varepsilon \in [\theta, 1+\theta] \end{cases}$, so that $J(S,\theta) = \begin{cases} 0, S = 0 \\ S + \theta, S \in (0,1] \end{cases}$,

where parameter $\theta \in [0,1)$ is fixed and represents the measure of consumers with $\varepsilon = 1$.

Then time 2 equilibrium conditions in Eqn (18) can be rewritten as:

(26a) $(1-x)\overline{F} \le c_S$, if $S^* = 0$;

(26b) $\min[1 - S^* - \theta, \overline{F}] = c_S(1 - S^*)/(1-x)$, if $S^* < x$;

(26c) $\min[1 - x - \theta, \overline{F}] = c_S + f_N^* - f_G^*$, if $S^* = x$ and $1 - x - \theta > 0$.

Consider "partial segregation" equilibrium equation (26b). The LHS is non-linear in S^*, while the RHS is a straight line with the slope $-c_S/(1-x)$. Graphically, the solution to Eqn (26b) is given by the set of the intersection points between the piece-wise linear LHS and the RHS, the downward sloping line (see Figure 4).

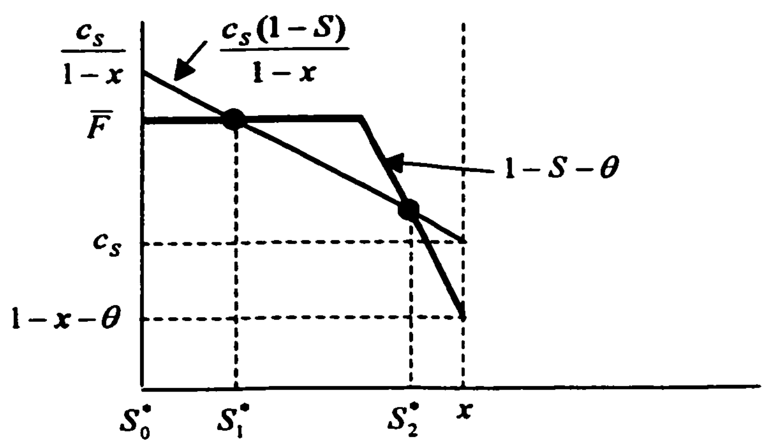

Figure 4. Multiple Equilibria at Time 2

From Figure 4 and Eqn (26), it can be shown that multiple equilibria with $S^* < x$ emerge when[44]

(27) $c_S < \theta[c_S/(1-x)]/[1-c_S/(1-x)] < \overline{F} < c_S/(1-x) < 1$.

Below we elaborate on the string of inequalities in (27). We must have $c_S/(1-x) < 1$ to assure that the downward sloping portion of the LHS is steeper than the RHS. This happens when either the IP cost or the supply of variety N is "low". Condition $\overline{F} < c_S/(1-x)$ guarantees that the penalty is not "too high", so as to preclude any possibility of cheating at a profit when $S^* \to 0$. Restriction $\theta[c_S/(1-x)]$ $/[1-c_S/(1-x)] < \overline{F}$ states that the expected penalty is not "too low" so that the IP retailers are willing to support higher levels of S^*. And finally, condition $c_S < \theta$ $[c_S/(1-x)]/[1-c_S/(1-x)]$ can be rewritten as $1-x-\theta < c_S$. The condition implies that the equilibrium with $S^* = x$ is not feasible.[45]

When all inequalities in (27) hold we have the following set of equilibria:

- $S_0^* = 0$, "no segregation";
- $S_1^* = 1-(1-x)\overline{F}/c_S$, low "partial segregation";
- $S_2^* = 1-\theta(1-c_S/(1-x))^{-1}$, high "partial segregation".

It is worthy of note that the low "partial segregation" equilibrium is unstable while equilibrium with $S^* = S_2^*$ is stable in the sense of Marshallian stability.[46] Namely, the expected price premium is a locally increasing (decreasing) function of S when $S^* = S_1^*$ ($S^* = S_2^*$):

$$\partial\{p_L - p\}/\partial S|_{S=S_1^*} = \left(q_b(x,S)\overline{F}\right)_S > 0, \text{ and}$$

$$\partial\{p_L - p\}/\partial S|_{S=S_2^*} = \left(q_b(x,S)(1-S-\theta)\right)_S < 0,$$

[44] These conditions are necessary to assure that the LHS and RHS intersect at two distinct points and that these points lie in $(0,x)$.

[45] We assume that for some other θ, $1-x-\theta > c_S$ holds to assure that $x^* > 0$ (see the subsection on equilibrium at planting).

[46] For an introductory textbook treatment of stability concepts in economics see Silberberg (pp. 596-598).

where the subscripted S denotes differentiation. The uninteresting equilibrium with $S_0^* = 0$ is neither stable nor unstable.[47] Also, observe that $\partial S_1^* / \partial x > 0$ while $\partial S_2^* / \partial x < 0$. We will return to this point later in the paper.

Now we proceed to analyze equilibrium at time 3 when the levels of segregation $S^* = S_1^*$ and $S^* = S_2^*$ were chosen at time 2. Rewriting the time 3 equilibrium conditions as stated in Eqn (13) we have:

(28a) $(p_L - p)^* = q_b(x, S^*)\overline{F}$, and $q_a(S^*, L^*)(1 - L^* - \theta) = \overline{F}$, if $L^* > S^*$;

(28b) $(p_L - p)^* = q_b(x, S^*)(1 - S^* - \theta)$, if $L^* = S^*$,

Clearly, when $S^* = 0$ no labeled products will be offered for sale at time 3 since cheating cannot be profitable (see the second equation in (28a)).

When $S^* = S_1^*$ we have $1 - J(S_1^*, \theta) = (1 - x)\overline{F} / c_S - \theta > \overline{F}$, where the last inequality follows from one of the conditions in (23).[48] In this case, the expected penalty does not deter the non-IP retailers from false labeling and Eqn (28a) holds. The share of non-GMO labeled food products, $L^*_{S_1^*}$, is then given by:

$$L^*_{S_1^*} = [(1 - \theta)(c_S - (1 - x)\overline{F})] / [c_S \overline{F} + c_S - (1 - x)\overline{F}] \in (S_1^*, 1 - \theta).$$

Then the share of (ex-ante) falsely labeled supply at time 3 is given by:

$$1 - q_a(S_1^*, L^*_{S_1^*}) = 1 - S_1^* / L^*_{S_1^*} = 1 + [\overline{F}((1 - x) / c_S - 1) + 1] / (1 - \theta).$$

We remind the reader that at time 2 the share of supply of variety N at harvest, x, is taken as given. Then we write:

$$\partial\{1 - q_a(S_1^*, L^*_{S_1^*})\} / \partial \overline{F} = [(1 - x) / c_S - 1] / [1 - \theta] > 0, \text{ and}$$

$$\partial\{1 - q_a(S_1^*, L^*_{S_1^*})\} / \partial c_S = -\overline{F}(1 - x) / [c_S^2 (1 - \theta)] < 0,$$

which can also be immediately seen using result 2. Observe that we have $J_L(.) = 1 > c_S / (1 - x)$, where the last inequality follows from assumptions in (27). This condition along with the assumptions made in the example is precisely what is needed for result 2 to hold.

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[47] In this paper, we will pay little attention to the "no segregation" equilibrium because the problem of false labeling is assumed away if none of variety N is processed separately.

[48] Rewrite $(1 - x)\overline{F} / c_S - \theta > \overline{F}$ as $\overline{F}((1 - x) / c_S - 1) > \theta$, or $\overline{F} > \theta[c_S / (1 - x)] / [1 - c_S / (1 - x)]$.

When $S^* = S_2^*$, the penalty is high compared to the revenues earned by cheating. No food products are falsely labeled as non-GMO because we have $1 - J(S_2^*, \theta)$ $= \theta(1 - c_S/(1-x))^{-1} - \theta < \overline{F}$.[49]

Also, note that the premiums paid for type N food products are identical under $S^* = S_1^*$ and $S^* = S_2^*$. Namely, we always have $p_L^* - p^* = c_S$. Formally, this is so because $S^* = S_1^*$ appears as a solution to $q_b(x, S_1^*)\overline{F} = c_S$, while solving $q_b(x, S_1^*) \cdot [1 - S_1^* - \theta] = c_S$ yields the equilibrium with $S^* = S_2^*$. Note that the RHS of the last two equations are the same. This observation, along with the fact that θ is fixed and known with certainty at time 2, explains why the price premium paid for the labeled product remains identical at time 3. The equilibrium with $S^* = S_1^*$ is predicated upon sufficiently low $\overline{F}$ so that expected revenues generated by following the IP practices and avoiding them are equated at time 2. Note that it is common knowledge that some non-IP retailers will falsely label their food products (i.e., without knowing the exact identity of the food product) at time 3 if $S^* = S_1^*$ at time 2. Under both "low" and "high" partial segregation equilibria, competitive retailers set the expected price premium paid for labeled food equal to the segregation cost, c_S. But θ is a constant, and therefore the price differential between labeled and unlabeled food products envisioned at time 2 is always equal to the actual price premium paid at time 3.

In part (b) of the example (see page 35 for the beginning) we continue to use the same set-up with the exception of inequality (27), which no longer holds.

EXAMPLE 1, Part (b).
On the other hand, the "no segregation" with $S_0^* = 0$, the "partial segregation" with $S_1^* = 1 - (1-x)\overline{F}/c_S$, and the "full segregation" equilibrium with $S_2^* = x$ exist when

(29) $\overline{F} < c_S/(1-x)$ and $\min[1 - x - \theta, \overline{F}] \geq c_S$.

---

[49] Rewrite $\theta(1 - c_S/(1-x))^{-1} - \theta < \overline{F}$ as $\theta[c_S/(1-x)]/[1 - c_S/(1-x)] < \overline{F}$.

The first condition in (29) has already been discussed (see page 34). The second one stipulates that at $S^* = x$ the adopters of IP- practices will agree to pay a positive premium for variety N. Here, under $S^* = S_1^*$ false labeling will take place. Similar to the previous case, $\overline{F}$ is sufficiently low to put a cap on profits earned by IP retailers. To prove that, we rewrite $1 - J(S_1^*, \theta) = (1-x)\overline{F}/c_S - \theta \geq \overline{F}$ as follows:

(30) $[\overline{F}/c_S][1-x-c_S] \geq \theta$.

From the conditions in (29) we know that $\overline{F}/c_S \geq 1$ and $1-x-c_S \geq \theta$, which implies inequality (30).

When $S^* = S_2^* = x$, some (none) of the non-IP food products will be labeled as type N food if $1-x-\theta \geq (<)\overline{F}$. Note that the premium paid for the labeled product is larger in the "full segregation" equilibrium. As before, when $S^* = S_1^*$ the (expected) price premium for labeled food items is given by $(p_L - p)^* = c_S$. When $S^* = S_2^*$, we have $(p_L - p)^* = \min[1-x-\theta, \overline{F}] \geq c_S$. Of course, in general, a higher value of S^* does not have to be positively associated with the higher premium.[50]

The next example shows that multiple equilibria may also exist in the absence of the "non-linearities" introduced by the penalty for false labeling and/or non-trivial mass of indifferent consumers.

EXAMPLE 2. Now take $H(1) = 1$ so that the mass of indifferent consumers is equal to zero. Then equilibrium condition (21) can be written as:

(31a) $1 - x \leq c_S$, if $S^* = 0$;

(31b) $\min[1 - J(S^*), \overline{F}] = c_S \dfrac{1-S^*}{1-x}$, if $S^* < x$;

(31c) $1 - J(x) = c_S + f_N^* - f_G^*$, if $S^* = x$.

[50] In part, it depends on the local curvature of the function $J(.,\theta)$.

Imagine that the graph of $\min[1-J(S),\overline{F}]$ looks as depicted in Figure 5. Then the multiplicity of equilibria is apparent.

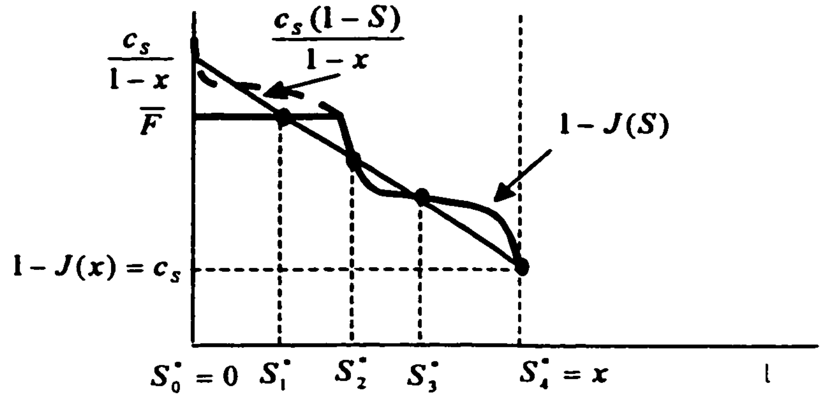

Figure 5.

Throughout our analysis, we held the share of variety N at harvest, x, fixed. Our next goal is to *endogenize* this variable. So we now turn to characterizing equilibrium at planting.

Equilibrium at Planting

At time 1, the rational and competitive farmers allocate the land between the two varieties until the expected net revenues per acre are equal. Like the retailers, the farmers weigh pros and cons of planting N versus G variety. On the production side, variety G provides an immediate cost advantage. However, variety N is typically preferred by most consumers (except for those that are indifferent between the two varieties). Formally, the per unit profit from planting crop N is given by $\max[f_N, f_G]-c_N$. The $\max[.,.]$ statement signifies that retailers weakly prefer variety N to variety G. Therefore, the variety N grower will always be able to convert his supply into the market which offers a higher price.[51] On the other hand, the per unit profit from planting G crop is given by $f_G - c_G$. From "full segregation" equilibrium equation (21c) we know that:

[51] This max[.,.] statement becomes operative and essential when we introduce uncertainty regarding aggregate demand at time 3.

$$(32)\quad \begin{aligned}&\max[f_N - f_G, 0]\\ &= \max[\min[1 - J(x), \bar{F}] - c_S, 0] \cdot \Pr(S^* = x)\end{aligned}$$

Observe that a positive premium for variety N at time 2 is conditioned on the outcome that all of variety N crop is processed separately. This becomes important when the "full segregation" equilibrium is not unique and other equilbria with $S^* < x$ exist at harvest. This model requires considerably more structure to induce a probability distribution over the possible equilibrium values of S^* emerging at time 2.[52] Instead, we characterize the equilibrium at time 1 in terms of an upper bound on acres planted to variety N, x^*. Understanding the behavior of an upper bound on equilibrium acreage allocation is important because we always have $x^* = \bar{x}$ when the highest attainable share of type N crop is processed using IP practices at time 2. Note that, in general, we have:

$$\max[\min[1 - J(x), \bar{F}] - c_S, 0] \cdot \Pr(S^* = x) \le \max[\min[1 - J(x), \bar{F}] - c_S, 0].$$

Therefore, $\exists\, \bar{x} \ge x^*$ such that:

$$(33)\quad \max[\min[1 - J(x), \bar{F}] - c_S, 0] \cdot \Pr(S^* = x^*) = \max[\min[1 - J(\bar{x}), \bar{F}] - c_S, 0],$$

since the RHS of the last equation is non-increasing in $\bar{x}$.

In planting equilibrium, a grower should be indifferent between sowing an acre to variety N or G. The equilibrium price premium paid for variety N at harvest is adjusted until it is equal to the production cost differential delivered by variety G. Equating the revenues from growing variety N, $\max[f_N, f_G] - c_N$, and G, $f_G - c_G$, and substituting Eqn (32) and (33), we obtain the following condition characterizing the upper bound on equilibrium x^*:

$$(34)\quad \max[\min[1 - J(\bar{x}), \bar{F}] - c_S, 0] = c_N - c_G,$$

where $\bar{x}$ is an an upper bound of equilibrium x^*, $x^* \in (0, \bar{x}]$.

Observe that the LHS of Eqn (34) is (weakly) decreasing in $\bar{x}$ which adjusts to equate the price premium for variety N with the cost advantage provided by variety G. We infer from Eqn (34) that variety N is planted only if

[52] When false labeling takes place in all outcomes: $S^* = x$ and $S^* < x$, the probability that $S^* = x$ is unique and equal to $(c_N - c_G)/(\bar{F} - c_S)$. However, the equilibrium acreage allocation, x^*, is then indeterminate unless some special assumptions about growers' behavior are stated.

(35) $\overline{F} \geq c_S + c_N - c_G$.

The expected penalty for false labeling must exceed the sum of segregation cost and the excess production expenditures associated with variety N to render it worthwhile to grow variety N. Observe that, otherwise, we have $\bar{x} = 0$ which implies that $x^* = 0$ as well. Hereafter, we make the assumption that condition (35) holds. Eqn (34) then reduces to:

(36) $1 - J(\bar{x}) = c_S + c_N - c_G$,

Inverting demand function, $J(.)$, yields:

(37) $\bar{x} = H(1 - c_S - (c_N - c_G))$.

It is immediate from (37) that $\bar{x}$ varies inversely with the segregation cost, c_S, and the cost differential at planting, $c_N - c_G$. Interestingly, $\bar{x}$ does not depend on $\overline{F}$. However, we shall see that $\overline{F}$ is likely to affect the level of $\bar{x}$ when there exists uncertainty at planting.

Unfortunately, we cannot say how result 2 is transformed when supply of variety N at harvest, x^*, is endogenous. Characterizing x^* in terms of its upper boundary, $\bar{x}$, is not sufficient to make inferences about x^* itself:

(38) $x^* = H(1 - c_S - (c_N - c_G)/\Pr(S^* = x))$

The reason is that we do not have enough information to determine the behavior of $\Pr(S^* = x^*)$ as a function of $\overline{F}$ and c_S. To illustrate how the conclusion of result 2 may be reversed when supply of variety N, x, is endogenous and responds to a (anticipated) change in $\overline{F}$ and c_S, we continue to use the technology from Example 1(b).

EXAMPLE 1, Part (b). (continuation)

Consider the environment described in Example 1(b). However, now we treat $x = x^*$ as an endogenous variable determined within the model at time 1, when planting takes place. Using Eqn (38) we obtain:

$$x^* = 1 - \theta - c_S - (c_N - c_G)/\Pr(S^* = x).$$

Assuming that $\partial \Pr(S^* = x)/\partial \overline{F}$ is well defined, we can write:

$$\frac{\partial x^*}{\partial \overline{F}} = \frac{c_N - c_G}{[\Pr(S^* = x)]^2} \frac{\partial \Pr(S^* = x)}{\partial \overline{F}}.$$

Then differentiating $S_1^* = 1-(1-x^*)\overline{F}/c_S$ (we remind the reader that S_1^* is the level of segregation in the "partial segregation" equilibrium) with respect to $\overline{F}$, we have:

$$\frac{\partial S_1^*}{\partial \overline{F}} = \frac{1}{c_S}\left(\frac{\partial x^*}{\partial \overline{F}}\overline{F} - (1-x^*)\right)$$

$$= \frac{1}{c_S}\left(\frac{c_N - c_G}{[\Pr(S^* = x)]^2} \frac{\partial \Pr(S^* = x)}{\partial \overline{F}}\overline{F} - \theta - c_S - \frac{c_N - c_G}{\Pr(S^* = x)}\right).$$

We cannot ascertain the sign of the last expression without further assumptions. Hence, we cannot apply lemma 2 to infer how the share of false labels, $1-q_a(S_1^*, L^*)$, depends on $\overline{F}$. A similar conclusion holds when c_S is increased by a small amount (the sign of $\partial S_1^* / \partial c_S$ is indeterminate as well).

In part one of this paper, we have shown that, counter-intuitively, the fear of penalties or an increase in labeling monitoring efforts may actually increase the share of false labels. This may happen when the expectation of the price premium for non-GMO labeled food variety, calculated in the segregation stage, falls as the share of non-GMO crop processed separately declines. Subsidizing the costs of segregation can trigger a similar effect. Alternatively, these "perverse" relationships between the expected penalty/segregation costs and the extent of false labeling may be caused by the acreage allocation response. Nonetheless, competitive markets are likely to leave some room for governmental intervention at the early stages of the production process that will improve market provision of information and decrease the share of non-IP produced foods labeled as GMO-free.

The previous analysis has been conducted based on a heroic assumption that there is no uncertainty faced by retailers and farmers (so far the only source of uncertainty for farmers has arisen due to the multiplicity of equilibria at time 2). We now relax this assumption in several ways. In part two of the paper, the demand shifter, parameter θ, "average" penalty, $\overline{F}$, and the costs of segregation, c_S, will be perceived as random variables that are realized at time 3, and time 2, respectively. Furthermore, we will consider how signals about future realizations of these random variables received by farmers and retailers prior to making their production decisions affect equilibrium outcomes. First, we will define the nature of uncertainty and rewrite the equilibrium equations at time 2, Eqn (21), and at time 1, Eqn (34), given the uncertainty faced by retailers and farmers. Then we will inquire into how the main insight of part one of this paper, stated in Result 2, fares in the presence of uncertainty. We will also investigate the effects of a less informative environment on production decisions.

Part 2. Effects of Uncertainty

Uncertainty and Equilibrium at Harvest and at Planting

First, we specify the manner in which uncertainty enters the economic environment described in part one. At various points in the following discussion, we will focus on uncertainty regarding the values of three variables: θ, $\overline{F}$, and c_S. The preferences distribution conditioning parameter $\theta \in [0,1]$ is held to be a random variable with the signal-conditioned probability distribution $R_\theta(\theta \mid \xi)$, where signal $\xi \in [\underline{\xi}, \overline{\xi}]$ is received at time 2, $R_\theta(0 \mid \xi) = 0$ and $R_\theta(1 \mid \xi) = 1 \;\; \forall \xi \in [\underline{\xi}, \overline{\xi}]$. Thus parameter θ summarizes the uncertainty surrounding the aggregate demand through a stochastic shift of the distribution of types realized at time 3. We assume that the distribution of posterior beliefs, $R_\theta(\theta \mid \xi)$, is such that $\partial R_\theta(\theta \mid \xi) / \partial \xi \leq 0 \;\; \forall \xi \in [\underline{\xi}, \overline{\xi}]$, $\forall \theta \in [0,1]$. That is, a higher signal makes the higher realizations of θ more likely consequently, letting the retailers know that the demand for type N food is likely to be weaker at time 3. Signal ξ represents the information available to retailers before they make segregation decisions at time 2. At that time, retailers observe a signal ξ about the consumers' demand at time 3, and use it to update their posterior beliefs about the probability distribution of θ, $R_\theta(\theta \mid \xi)$. This is illustrated in Figure 6.

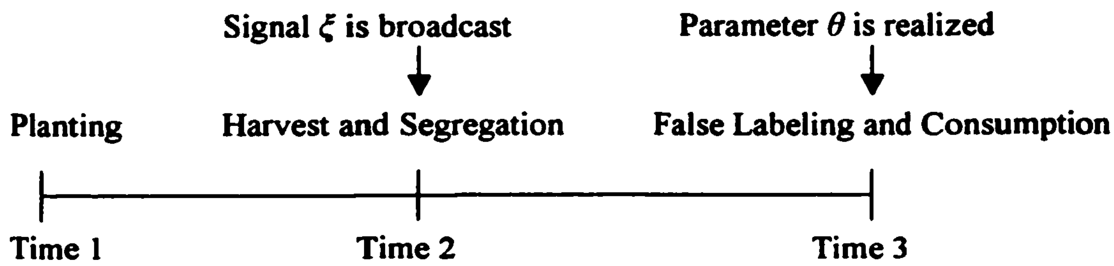

Figure 6. Timing of events and arrival of information

Now we rewrite equilibrium conditions at time 2 and at time 1 assuming that parameter θ is a random variable as defined above.[53] We remind the reader that retailers and farmers are taken to be risk-neutral. Following the steps used to derive time 2 equilibrium condition, Eqn (21), but using *expected* values of the per unit profits, we obtain:[54]

(39a) $(1-x)\overline{F} \le c_S$, when $S^* = 0$;

(39b) $q_b(x, S^*)E_2\{\min[\max[1-J(S^*,\theta),0],\overline{F}] \mid \xi\} = c_S$, when $S^* \in (0, x)$;

(39c) $E_2\{\min[\max[1-J(x,\theta),0],\overline{F}] \mid \xi\} = c_S + f_N^* - f_G^*$, when $S^* = x$,

where $E_2\{. \mid \xi\}$ indicates that the expectation is taken conditional on the information available at time 2 and with respect to the signal ξ updated posterior beliefs, $R_\theta(\theta \mid \xi)$.

When forming their expectations at time 1 about the market conditions at harvest (time 2), the farmers are assumed to know both the signal-conditioned posterior $R_\theta(\theta \mid \xi)$ and the probability distribution of signals, $R_\xi(\xi)$. The equilibrium condition that determines an upper bound on acres sown to variety N, x^*, analogous to Eqn (34), then becomes:

(40) $E_1 \max[E_2\{\min[\max[1-J(\bar{x},\theta),0],\overline{F}] \mid \xi\} - c_S, 0] = c_N - c_G$,

where E_1 is the expectation operator conditional on the information available at time 1.

The crucial difference between the equilibrium conditions with and without uncertainty consists of the following. Normally, when calculating *expected* profits, retailers

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[53] Equilibrium conditions when there exists uncertainty regarding $\overline{F}$ and c_S look very similar and will be stated as needed.
[54] For the rest of the paper, we hold that for some θ we have $H(1,\theta) \le 1$, and hence, $J(1,\theta) \ge 1$, so that there may be a strictly positive mass of consumers who are indifferent between the two food varieties (see Eqn (10)).

and farmers consider various possible realizations of θ ($\bar{F}$, or c_S).[55] Then non-linearities of the LHSs of Eqn (39) and (40) in these variables, which arise due to the combinations of max[.,.] and min[.,.] statements, become critical. For example, consider equilibrium at planting. Observe how the two max[.,] statements in Eqn (40) reflect the fact that variety N has a potential to turn out to be a much "hotter" commodity than variety G at time points 2 and/or 3, while it will *never* be priced lower than variety G in the marketplace. Also, if for some low values of θ we have $1 - J(x^*, \theta) > \bar{F}$ then, even though assumption (35) holds, the expected penalty, $\bar{F}$, will enter the growers' calculation of the expected price premium to be received for variety N at harvest. Contrast this with the equilibrium acres sown to variety N in the absence of uncertainty as given by Eqn (37).

Uncertainty and Effects of Penalty and Segregation Costs

In the presence of uncertainty, the analysis is considerably more complicated because retailers do not know for sure whether false labeling will be profitable at time 3, and therefore, Result 2 loses its sharpness. Observe that, in the case of full certainty (see Eqn (22b)), it is precisely in the "false labeling" equilibrium that the relationships between the level of segregation and the expected penalty (segregation costs) are at odds with prior intuition. Such "odd" relationships were responsible for the failure of a policy striving to reduce the amount of fraud by means of increasing penalty or rebating IP costs (see the discussion surrounding Result 2). However, in the case of uncertainty, retailers integrate over all probable outcomes at time 3 when making their decisions to invest in the IP processing at time 2 (see Eqn (39)). But then the relationships between S^* and $\bar{F}$, and S^* and c_S are likely to depend on the local curvature of function $J(.,\theta)$ at $S = S^*$ and, therefore, typically, be ambiguous.

Given the timing of the production decisions, we can write $S^* = S(x^*, c_S, \bar{F}, \xi)$ and $x^* = x(c_S, \bar{F}, c_N - c_G)$. Since, $\partial S / \partial k$, where $k = x^*, c_S, \bar{F}, \xi$, can plausibly be of either sign (see Examples 1 and 2 and the discussion of the non-monotonicity of Eqn (18) in S^*)

[55] Here we focus on the uncertainty regarding θ. Later on we consider environment where $\bar{F}$ and c_S are uncertain.

the effects of an increase in c_S, and $\bar{F}$ on S^* are, in general, indeterminate. Formally, we are interested in the sign of

(41) $dS^* / dk = \partial S / \partial k + [\partial S / \partial x^*][\partial x^* / \partial k]$, where $k = c_S, \bar{F}$.

In the manner of the previous analysis, we refer to the terms in (41) $\partial S / \partial k$ ($[\partial S / \partial x^*][\partial x^* / \partial k]$) as the direct (indirect) effect of an increase in k on S^*. The direct effect on S^*, given by $\partial S / \partial k$, transpires because the environment *at time 2* changes. The indirect effect, given by $[\partial S / \partial x^*][\partial x^* / \partial k]$, works its way through the acreage allocation response *at time 1*.

To say more about Eqn (41), we define the function $G(S, x, c_S, \bar{F}, \xi)$ as follows (see time 2 partial segregation equilibrium condition (39b)):

(42) $$G \equiv \frac{1-x}{1-S} E_2\{\min[\max[1 - J(S,\theta), 0], \bar{F}] \mid \xi\} - c_S.$$

Then time 2 equilibrium with $S^* \in (0, x^*)$ is given by: $G(S^*, x^*, c_S, \bar{F}) = 0$. Using implicit function theorem, we can write: $\partial S / \partial k = -G_k / G_S$ and $\partial S / \partial x = -G_x / G_S$, where the subscripted "k" and "S" denote differentiation. Substituting these in (41), we have:

(43) $$\frac{dS^*}{dk} = -\frac{1}{G_S}(G_k + G_x \frac{\partial x^*}{\partial k}).$$

Several individual terms in (43) can be signed unambiguously: $G_{\bar{F}} \geq 0$ (where it exists), $G_{c_S} < 0$, and $G_x \leq 0$, by a straightforward differentiation of the RHS of (42). Even though we can only determine an upper bound of x^*, it is safe to conjecture that $\partial x^* / \partial \bar{F} \geq 0$ and $\partial x^* / \partial c_S \leq 0$ are likely to hold in most cases.[56] And so, the direct and indirect effects are likely to be working in the opposite directions.

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[56] As was pointed out, it is straightforward to see from Eqn (40) that $\partial \bar{x} / \partial \bar{F} \geq 0$ and $\partial \bar{x} / \partial c_S \leq 0$ (where they exist). Of course, it is wrong to blindly surmise that such relationships also hold for x^* when full segregation equilibrium at time 2 is not unique. However, harking to condition (20), observe that it is likely that the probability of the "full segregation" equilibrium at time 2, $\Pr(S^* = x)$, is increasing in $\bar{F}$ and decreasing in c_S. Then our conjectures regarding the effect of $\bar{F}$ and c_S on x^* seem to have a firmer foundation.

The function $G(S, x, c_S, \overline{F}, \xi)$ is the expectation conditioned on the signal ξ of the price premium paid for the non-GMO labeled food item net of the segregation costs. Intuitively, we expect this price premium to be a decreasing function of S^*, i.e., $G_S \leq 0$. Then we have $dS^* / d\overline{F} \geq 0$ and $dS^* / dc_S \leq 0$ when the direct effect dominates the indirect effect (in absolute values). Some conditions guaranteeing that the direct effect dominates are presented in Appendix B. Alternatively, imagine that the change in $\overline{F}$ or c_S takes place at time 2, which was not expected at time 1. Then the "perverse" effect of an increase in $\overline{F}$ or c_S on S^* is possible only if $G_S > 0$.[57] However, observe that if $\exists S' \in [0, x)$ such that $G(S', x^*, c_S, \overline{F}) = 0$ and $G_S(S', x^*, c_S, \overline{F}) > 0$ then $\exists S'' \in (S', x)$ such that $G(S'', x^*, c_S, \overline{F}) = 0$ or $G(x^*, x^*, c_S, \overline{F}) \geq 0$, and hence an equilibrium with a higher level of segregation is achievable at time 2. Summarizing, the negative effect of raising a penalty for false labeling or subsidizing the segregation costs occurring due to an increasing expected price premium can be reversed by forcing the market to a higher equilibrium value of S^* at time 2.[58]

To illustrate the effects of rebating the costs of the IP practices and raising the expected penalty on the level of segregation when there exists uncertainty regarding the value of θ, we continue to use the setting from Example 1. The example to follow demonstrates how the presence of uncertainty may "turn around" the relationships between $\overline{F}$ (c_S) and the share of falsely labeled products established in part one of the paper.

EXAMPLE 3. Recollect that we take $J(S, \theta) = \begin{cases} 0, S = 0 \\ S + \theta, S \in (0,1] \end{cases}$. However, we no longer hold that there is no uncertainty about the value of θ. We specify distributions $R_\theta(\theta \mid \xi)$ and $R_\xi(\xi)$ because, clearly, the equilibrium level of x, which is established at time 1, will differ

[57] This is so because the term $[G_x][\partial x^* / \partial k]$ falls out in (43).

[58] Note that there is a possibility that the interaction between the effect triggered by the acreage allocation (the indirect effect) and the "perverse" direct effect will lead to the intuitively expected positive response of the segregation level.

depending on the growers' expectations about the environment at harvest. Assume that there are only two possible realizations of signal ξ : ξ_1 which is observed with probability p_1^{ξ}, and ξ_2 with probability $p_2^{\xi} = 1 - p_1^{\xi}$. From observing the signal ξ_1 at time 1, it can be inferred that $\theta = \theta_L$ at time 3 with probability 1. While the signal ξ_2 implies that the distribution of θ is concentrated at two points: $\theta = \theta_L$ with probability p_L^{θ}, and $\theta = \theta_H$ with probability $p_H^{\theta} = 1 - p_L^{\theta}$, where $\theta_L < \theta_H$. This stochastic structure is depicted in Figure 7.

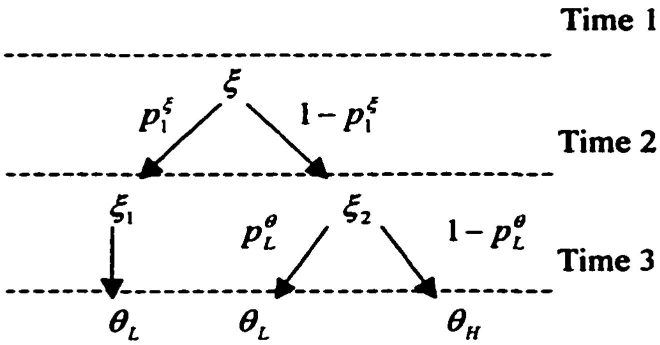

Figure 7. Distributions of time 2 signals ξ and parameter θ

We remind the reader that we always have $x^* = \bar{x}$ whenever the "full segregation" equilibrium ($S^* = x^*$) for each signal ξ broadcast at time 2 is unique. To make the following analysis definitive, we carefully choose the parameters so that the equilibrium when *all* of variety N is processed through IP is, in fact, unique. In addition, we allow for an outcome where *false* labeling is profitable at time 3. In the manner of Example 1, the set of the "partial segregation" equilibria with $S^* \in (0, x^*)$ is given by the points of intersection between the two lines: piece-wise linear $E_2\{\min[\max[1 - S^* - \theta, 0], \bar{F}] \mid \xi\}$ and a straight line $c_S(1 - S^*)/(1 - x)$. A diagrammatic exposition of such equilibrium conditions at time 2 is presented in Figure 8.

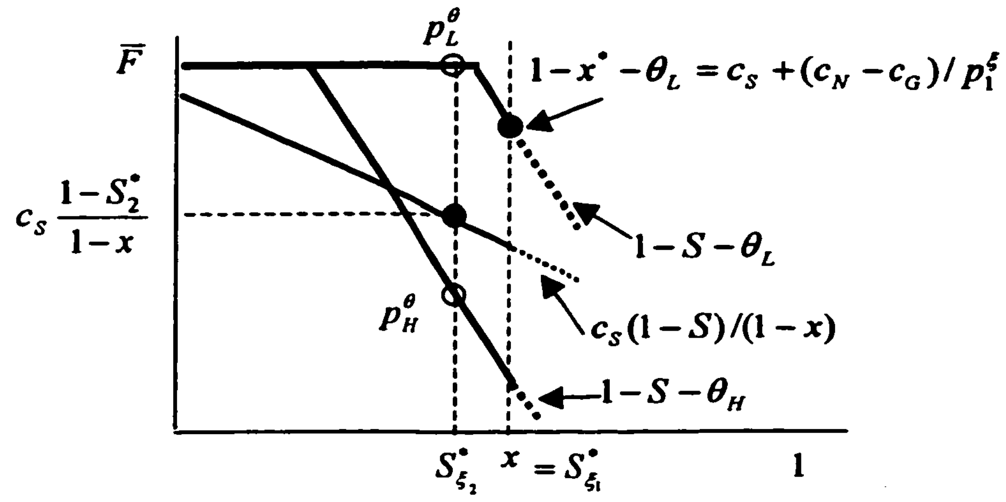

Figure 8.

We analyze the time 2 equilibrium conditions as stated in Eqn (39) for each realization of signal ξ. If $\xi = \xi_1$ at time 2 then equilibrium equation (39b) reduces to

$$1-x^{*}-\theta_L = c_S + f_N^{*} - f_G^{*}$$

when the following conditions hold:

(44) $\overline{F} > 1-x^{*}-\theta_L > c_S$ and $\overline{F} > \dfrac{c_S}{1-x^{*}}$.

That the latter condition in (44) is necessary for the signal ξ_1-conditioned "full segregation" equilibrium, $S_{\xi_1}^{*} = x^{*}$, to be unique can be seen from Figure 8. Observe that if $\overline{F} < c_S/(1-x^{*})$ then an equilibrium with $S^{*} < x^{*}$ always exists. Therefore, the inequalities in (44) are sufficient to ensure the *uniqueness* of the "full segregation" equilibrium when signal $\xi = \xi_1$ is received at time 2. In addition, we immediately know that no labels will be false at time 3 as we always have $L^{*} = S_{\xi_1}^{*}$.[59]

When the other signal is observed at time 2, $\xi = \xi_2$, the "partial segregation" equilibrium equation Eqn (39b) can be expressed as:

[59] See the first condition in (44) in the light of Eqn (39) to infer that false labeling cannot be profitable when $\xi = \xi_1$ at time 2.

(45) $\min[\max[1-S^*_{\xi_2}-\theta_L,0],\overline{F}]\cdot p^\theta_L+\min[\max[1-S^*_{\xi_2}-\theta_H,0],\overline{F}]\cdot p^\theta_H=c_S/q_b(x,S^*_{\xi_2})$.

As was mentioned before, to motivate our interest in this example, we allow for the possibility that some of the non-IP food supply is *falsely* labeled at time 3, when the demand for type N food is "high" (i.e., θ is low.) We are seeking such restrictions on the parameters that false labeling takes place when we have $S^*=S^*_{\xi_2}<x^*$ at time 2 and $\theta=\theta_L$ at time 3. To this end, we rule out the solution to (45) such that $1-S^*_{\xi_2}-\theta_L<\overline{F}$ which means that the expected penalty is sufficiently high to prevent all retailers from cheating (even in the state when preferences are shifted towards type N food.) Let $S'<x^*$ be such a solution to (45) with $1-S'-\theta_L<\overline{F}$. Then we have:

(46) $(1-S'-\theta_L)p^\theta_L+(1-S'-\theta_H)p^\theta_H=c_S/q_b(x,S')$.

After a bit of algebra we obtain: $S'=1-E[\theta\,|\,\xi_2]/[1-c_S/(1-x)]$. Observe that time 2 equilibrium with $S=S'$ is not feasible if $1-S'-\theta_L\geq\overline{F}$. The latter inequality always holds whenever

(47) $E_2[\theta\,|\,\xi_2]-\theta_L\geq\overline{F}$,

since $1\geq\overline{F}>c_S/(1-x)$ is assumed to hold. The solution to Eqn (45) we are interested in is then given by:

(48) $\overline{F}p^\theta_L+(1-S^*_{\xi_2}-\theta_H)p^\theta_H=c_S/q_b(x^*,S^*_{\xi_2})$.

Solving for $S^*_{\xi_2}$, we obtain:

(49) $S^*_{\xi_2}=1-[\theta_H p^\theta_H-\overline{F}p^\theta_L]/[1-c_S/(1-x^*)]<x^*$,

where the last inequality will be validated later when time 1 equilibrium is considered, and we require that $0<1-J(S^*_{\xi_2},\theta_H)<\overline{F}$:

(50) $0<[\theta_H p^\theta_H-\overline{F}p^\theta_L]/[1-c_S/(1-x^*)]-\theta_H<\overline{F}$,

and $1-J(S^*_{\xi_2},\theta_L)>\overline{F}$, which, given assumption (47), always holds when:

(51) $c/(1-x^*)>p^\theta_L$.

Time 2 equilibrium with $S = S^*_{\xi_2}$ is unique when $\xi = \xi_2$ is received and conditions (44), (47), (50), and (51) hold. Note that false labeling takes place and we have $L^*_{\xi_2,\theta_L} > S^*_{\xi_2}$ when the demand for variety N turns out to be high at time 3, $\theta = \theta_L$ after signal $\xi = \xi_2$ is broadcast at time 2. None of the labels are false, $L^*_{\xi_2,\theta_H} = S^*_{\xi_2}$, if demand for variety N is low, $\theta = \theta_H$, at time 3.

Finally, we can turn to determining equilibrium at time 1. Planting time equilibrium condition (40) can be rewritten as (remember that we are choosing the parameters in order to have $x^* = \bar{x}$):

(52) $(1 - x^* - \theta_L - c_S)\cdot p_1^{\xi} = c_N - c_G$.

And the equilibrium acreage sown to variety N is then given by:

(53) $x^* = 1 - \theta_L - c_S - (c_N - c_G)/p_1^{\xi}$,

when the conditions in (44), (47), (50), and (51) hold. Note that x^* is a decreasing function of θ_L, c_S, and $c_N - c_G$, but it increases with the probability that signal ξ_1 is received at time 2.

For completeness, we substitute Eqn (53) in conditions (44), (50), and (51), and check their joint validity. Condition (44) holds when

(44') $\bar{F} > c_S + (c_N - c_G)/p_1^{\xi}$ and $\bar{F} > \dfrac{c_S}{\theta_L + c_S + (c_N - c_G)/p_1^{\xi}}$.

In the same way, condition (45) can be rewritten as:

(50') $0 < [\theta_H p_H^{\theta} - \bar{F} p_L^{\theta}]/[1 - \dfrac{c_S}{\theta_L + c_S + (c_N - c_G)/p_1^{\xi}}] - \theta_H < \bar{F}$.

Finally, after substituting for x^* (Eqn (53)), condition (51) becomes:

(51') $c_S/[\theta_L + c_S + (c_N - c_G)/p_1^{\xi}] > p_L^{\theta}$.

An example of the values of parameters that satisfy the inequalities in (44'), (47), (50'), and (51') is presented in Table 1. The equilibrium values are then given by: $x^* = 0.43$ and $S^*_{\xi_2} = 0.127$, and $L^*_{\xi_2,\theta_L} = 0.167$.

Table 1. Parameter values

$\overline{F}$	c_S	p_1^{ξ}	p_L^{θ}	$c_N - c_G$	θ_L	θ_H
0.56	0.22	0.8	0.2	0.2	0.1	0.81

Now we consider the effect of subsidizing the segregation costs on $S^*_{\xi_2}$. It is immediate from Eqn (53) that $\partial x^* / \partial c_S = -1$. Totally differentiating $S^*_{\xi_2} = S_{\xi_2}(x^*, c_S, \overline{F})$, as given by Eqn (49), with respect to c_S, yields:

$$dS^*_{\xi_2} / dc_S = \partial S_{\xi_2} / \partial c_S + [\partial S_{\xi_2} / \partial x^*][\partial x^* / \partial c_S]$$

$$= -[\theta_H p_H^{\theta} - \overline{F} p_L^{\theta}]/[1 - c_S/(1-x^*)]^2 \cdot [1 - x^* - c_S] < 0 .$$

In this case, subsidizing the IP costs will, in fact, raise the equilibrium share of variety N processed using the IP procedures when the signal ξ_2 is received at harvest. Hence, the objective of the government to minimize $E_1\{1 - q_a(S^*, L^*)\}$ will be fulfilled by such a measure. Also, the same result is achieved by increasing $\overline{F}$.[60]

In general, in the presence of uncertainty regarding θ, existing at times 2 and 1, conditions, needed for a result analogous to Result 2 to hold, become awkward and too cumbersome to entail an intuitive interpretation. This happens because of the interaction between the (signal-conditioned) probability distribution of θ, $R_{\theta}(\theta \mid \xi)$ and the price premium for variety N, $q_b(x, S) \cdot \min[\max[1 - J(S, \theta), 0], \overline{F}]$. Note that the price premium is usually non-monotone in S, unless one is willing to make quite restrictive assumptions about the functional form on the inverse demand function, $J(L, \theta)$. Nonetheless, several general propositions concerning the impact that uncertainty exerts on equilibrium outcomes can be formulated. So we proceed to analyze the effects of an increase in uncertainty regarding $\overline{F}$ in a partial equilibrium at time 2, holding that supply of variety N at that time, x, is taken as given.

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[60] Observe from (29) that $dS^* / d\overline{F} > 0$ which implies that we must have: $d\{S^*_{\xi_2} / L^*_{\xi_2, \theta_L}\} / d\overline{F}$ $= [d\{S^* / L^*\} / dS^*] \cdot [dS^* / d\overline{F}] + [\partial\{S^* / L^*\} / \partial L^*] \cdot [\partial L^* / \partial \overline{F}] > 0$.

Effects of Uncertainty and Signals at Harvest Time

In the manner of Kolstad, Ulen, and Johnson (1990), we consider the effects of uncertainty surrounding the penalty associated with making ("ex-post") false non-GMO statements. Imagine now that either the precise level of the success rate of discovering false labels, α, or the penalty imposed on cheating retailers, F, is not known with certainty at time 2. Consequently, the product of the two can be modeled as a random variable, denoted by $\tilde{F}$, which is realized at time 3. Let the uncertainty about $\tilde{F}$ be captured by a mean-preserving spread (m.p.s.) of the probability distribution of $\tilde{F}$ which is common knowledge.

Analyzing time 2 equilibrium conditions (39), we conclude the following. The "no segregation" equilibrium, $S^* = 0$, is more likely to exist as a result of an m.p.s. of the distribution of $\tilde{F}$. Observe that the condition for the "no segregation" equilibrium can now be written as:

(39a') $q_b(x,0)E_2\{\min[1,\tilde{F}] \mid \xi\} \leq c_S$, when $S^* = 0$.

The LHS of condition (39a') becomes smaller under an m.p.s. of the distribution of $\tilde{F}$ because it is convex in $\tilde{F}$.

The effect of an increase in uncertainty about $\tilde{F}$ on partial segregation equilibrium, $S^* \in (0,x)$, is ambiguous because the LHS of (39b) is, in general, non-monotone in S. However, in the "full segregation" equilibrium, $S^* = x$, more uncertainty about the level of $\tilde{F}$ implies a lower premium paid for variety N at harvest. This is so because the LHS of (39c) is concave in $\tilde{F}$ (see the $\min[.,.\tilde{F}]$ statement under the expectation operator). In addition, condition (14) that is necessary for the existence of equilibrium with $S^* = x$ and a positive price premium for variety N may no longer hold under an m.p.s of the distribution of $\tilde{F}$. Recapitulating, we have[61]

RESULT 3. Given the share of supply of variety N at harvest, x, an m.p.s. of the distribution of $\tilde{F}$ (weakly) lowers the price premium paid for crop N at time 2.

[61] Result 3 can be alternatively stated in terms of the second-order stochastically dominating transformation.

The intuition behind Result 3 consists of the following. The IP retailers lose most of the advantage accrued to the suppliers of pure type N food when the average penalty for cheating is minimal. However, a progressively higher penalty imposed on the retailers falsely labeling their products, eventually, has no further bearing on the profits made by the IP retailers. This is so because the premium earned by the IP retailers stops to increase with $\tilde{F}$ after $\tilde{F}$ reaches a certain level (which is given by $1-J(x,\theta)$). Such asymmetry implies that an increase in uncertainty (in the sense of an m.p.s.) regarding the fines for false labeling lowers the expected price premium paid for labeled food items at time 3.

Next, we look into the effects of an information signal regarding the future realizations of θ received at time 2 on the level of segregation. Observe that a local effect of a higher signal ξ realization on S^* depends on the local curvature of $J(.,\theta)$.[62] The effect of an increase in uncertainty represented by a second-degree stochastically dominating shift (SSD) of $R_\theta(\theta \mid \xi)$ is, in general, indeterminate as well as a result of a composition of $\min[.,.]$ and $\max[.,.]$ statements.

It may be of interest to investigate how an increase in uncertainty regarding the levels of $\tilde{F}$ and c_S affects the upper bound on equilibrium acres sown to variety N, $\bar{x}$, at time 1. We do this in the following subsection.

Effects of Uncertainty regarding $\tilde{F}$ and c_S at Planting Time

Here, we continue to hold the penalty for false labeling, $\tilde{F}$, to be a random variable realized at time 3 (see the discussion preceding Result 3). The (partial equilibrium) effect of an increase in uncertainty surrounding the penalty, $\tilde{F}$, on the price premium paid for variety N at harvest has already been summarized in Result 3. Now imagine that, at harvest, retailers receive a signal that informs them about the probability distribution of $\tilde{F}$. Then the question

[62] Note that the curvature of $J(.,\theta)$ is the opposite of that of $H(.,\theta)$ because $H(.,\theta)$ is increasing in the first argument. Note that, for example, in the US a large proportion of the population seems to have little concern over the GM content of their food. Then the cumulative distribution of types is likely to have a "roughly" convex overall shape. However, the shape of $H(.,\theta)$ cannot be ascertained in the lower range.

may be posed concerning the relationship between the nature of signals that will be received at time 2 (identified with the probability distributions of $\widetilde{F}$) and $\bar{x}$.[63]

Denote by $R^i_{\widetilde{F}}(\widetilde{F})$ the probability distribution of $\widetilde{F}$ when signal i is received *at time 2*. For clarity, we rewrite Eqn (40) when the main source of uncertainty stems from $\widetilde{F}$:

(54) $\quad \int \min[\max[1 - J(\bar{x},\theta),0],\widetilde{F}]dR_{\widetilde{F}}(\widetilde{F}) - c_S = c_N - c_G$.

Then the LHS of (54) is always larger under the distribution with $i = 1$ than under $i = 2$ if and only if $R^1_{\widetilde{F}}(\widetilde{F})$ second order stochastically dominates (SSDs) $R^2_{\widetilde{F}}(\widetilde{F})$, which is denoted as $R^1_{\widetilde{F}}(\widetilde{F}) \overset{ssd}{\geq} R^2_{\widetilde{F}}(\widetilde{F})$. Note that the signal 1 conditioned distribution, $R^1_{\widetilde{F}}(\widetilde{F})$, is less risky and shifts the probability mass towards higher realizations of $\widetilde{F}$. Such a shift raises the LHS of (54) because the expectation at time 2 is taken over an increasing and concave function of $\bar{F} \equiv \widetilde{F}$. Assume that retailers may receive either signal 1 or signal 2 at time 2. Then we conclude that $\bar{x}$ is larger under signal 1 when the distribution of $\widetilde{F}$ deduced from signal 1 SSDs the distribution of $\widetilde{F}$ deduced from signal 2.

Alternatively, we now assume that the segregation cost, $\widetilde{c}_S$, is as a random variable with probability distribution $R_{c_S}(\widetilde{c}_S)$ that is realized *at harvest*. One can imagine several factors contributing to the uncertainty about the unit cost of segregation existing at planting time. For example, uncertainty may be associated with the validity of GMO testing procedures, variation in required levels of purity, or increasingly volatile crop logistics at harvest. We rewrite Eqn (40) in the case when the costs of segregation are not known with certainty at time 1:

(55) $\quad \int \max[\min[\max[1 - J(\bar{x},\theta),0],\bar{F}] - c_S,0]dR_{c_S}(c_S) = c_G - c_N$.

From Eqn (55), observe that the expected price premium received by the variety N growers is convex in $c_S \equiv \widetilde{c}_S$. Therefore, an m.p.s. of the probability distribution of $\widetilde{c}_S$ raises the time 1 expectation of the price premium, and causes the (equilibrium) value of $\bar{x}$ to rise as well.

[63] This approach is a highly simplified version of a complete characterization of preferences over information signals developed by Athey and Levin (1998).

Note that the variety N grower benefits from an increase in uncertainty because he is insured against negative outcomes (i.e., "high" values of $\tilde{c}_S$), as the price premium for variety N cannot be negative. However, he can reap the benefits of growing a more expensive crop when the realization of $\tilde{c}_S$ is relatively "low" by earning a positive premium at harvest. To recap,

RESULT 4. Equilibrium value of $\bar{x}$ increases as a result of

a) a second-order stochastically dominating transformation of $R_{\tilde{F}}(\tilde{F})$;

b) a mean-preserving spread of distribution of $\tilde{c}_S$.

Still, so far we have not said anything about the effect of a more volatile *planting time* information about signals regarding the level of $\overline{F}$ on the upper bound on acres sown to variety N, $\bar{x}$. Note that signals informing retailers about the future possible realizations of $\overline{F}$ and θ can be studied in a similar manner. To simplify the notation, we hold that signal ξ may convey information about either θ or $\overline{F}$, where we assume one or the other at our convenience. Then we seek to understand how a stochastic shift of the distribution of time 2 information *signals*, $R_\xi(\xi)$, affects the upper bound on equilibrium acres sown to variety N, $\bar{x}$.

Effects of an Increase in the Signal Uncertainty at Planting

We proceed to analyze how an increase in the planting time uncertainty over the realizations of signal ξ received by the retailers at time 2 affects the upper bound on acreage allocation. First, we investigate the case with uncertainty regarding θ. For clarity, we rewrite Eqn (40) in the following form:

(56) $$\int_{\underline{\xi}}^{\bar{\xi}} \min[c_S + \int_0^1 \max[\min[J(\bar{x},\theta) - 1, 0], -\overline{F}] dR_\theta(\theta \mid \xi), 0] dR_\xi(\xi) = c_G - c_N.$$

Consider the map $R_\xi(\xi) \to R_\xi^1(\xi)$ that represents a SSD shift, $R_\xi(\xi) \overset{ssd}{\geq} R_\xi^1(\xi)$. Then we have:

RESULT 5. If $R_\theta(\theta \mid \xi)$ is decreasing and convex in $\xi \in [\underline{\xi}, \bar{\xi}]$ for each $\theta \in [0,1]$ then an upper bound on equilibrium acreage allocated to variety N decreases under a SSD shift $R_\xi(\xi) \to R_\xi^1(\xi)$.[64]

The condition on $R_\theta(\theta \mid \xi)$ in Result 5 has a straightforward intuitive interpretation. Here, it is slightly easier to think in terms of $\overline{R_\theta}(\hat{\theta} \mid \xi) = 1 - R_\theta(\hat{\theta} \mid \xi)$ which is the probability that $\theta \geq \hat{\theta}$ will occur at time 3 conditioned on the realized signal ζ. A higher signal implies that the higher values of θ become more likely. However, the concavity of $\overline{R_\theta}(\hat{\theta} \mid \xi)$ in ξ means that "good" and "bad" signals of equal magnitude will have asymmetric effects on the probability $\overline{R_\theta}(\hat{\theta} \mid \xi)$. Namely, the probability $\overline{R_\theta}(\hat{\theta} \mid \xi)$ rises less, when ξ is increased by $\Delta\xi$, than it falls when ξ is decreased by $\Delta\xi$. Therefore, when an uncertainty surrounding the possible realizations of the signal is greater, the growers will plant more variety N (in terms of an upper bound) to benefit from an increase in the uncertainty.

A remark is in order that the condition in Result 5 does not depend on the curvature of the function $\phi(\theta) = \max[\min[J(\bar{x}, \theta) - 1, 0], -\bar{F}]$ defined in the text of the proof of Result 5 (see appendix A). Consequently, Result 5 is somewhat stronger than similar results found in the literature in the sense that it does not require any particular assumptions on of the distribution of preferences among the population (see Saak and Hennessy (2001)).[65]

It is possible to weaken the condition on the signal-conditioned posterior $\overline{R_\theta}(\theta \mid \xi)$ in Result 5 by imposing more structure on $\phi(\theta)$. Applying the equivalence theorem for stochastic convexity / concavity (see Shaked and Shanthikumar (1994, p.173)) we have

[64] This analysis is a direct application of the concept of stochastic convexity/concavity in the usual stochastic ordering introduced by Shaked and Shanthikumar (1990) and further discussed in Shaked and Shanthikumar (1994).

[65] Saak and Hennessy (2001) investigate this issue in a environment where growers sell their crop directly to consumers.

RESULT 6. If $\phi(\theta) = \max[\min[J(\bar{x},\theta) - 1,0],-\bar{F}]$ is concave in θ for all $\theta \in [0,1]$ and $\int_0^1 R_\theta(\mu \mid \xi)d\mu$ is decreasing and convex in ξ then an upper bound on equilibrium acreage allocated to variety N decreases under a SSD shift $R_\xi(\xi) \to R_\xi^1(\xi)$.

Note that the function $\phi(\theta)$ is globally concave in θ if $\bar{F} = 1$ and $J_{\theta\theta}(x,\theta) \le 0$ for each $x \in [0,1]$. The latter condition appeared in the previous literature on the issue of the relationship between an increase in uncertainty and acreage allocation and has a very intuitive explanation (Saak and Hennessy (2001)).

Now we explore the case when there exist uncertainty regarding the level of $\bar{F}$. Result 5 can be easily adapted to the case when signal ξ contains information regarding likely values of $\bar{F}$ (instead of enhancing retailers' knowledge about future realizations of θ). To clearly indicate that we consider the case with uncertainty surrounding the level of $\bar{F}$, we rewrite time 1 equilibrium equation (40) as follows:

$$(57)\qquad \int_{\underline{\xi}}^{\bar{\xi}} \min[c_S + \int_0^1 \max[\min[J(\bar{x},\theta) - 1,0],-\bar{F}]dR_{\bar{F}}(\bar{F} \mid \xi),0]dR_\xi(\xi) = c_G - c_N .$$

Note that the LHS of (57) is (weakly) decreasing in $\bar{F}$. Then Result 5 can be reformulated as:

RESULT 7. If $R_{\bar{F}}(\tilde{F} \mid \xi)$ is increasing and concave in $\xi \in [\underline{\xi},\bar{\xi}]$ for each $\theta \in [0,1]$ then equilibrium upper bound on acreage allocated to variety N decreases under a SSD shift $R_\xi(\xi) \to R_\xi^1(\xi)$.

However, a stronger result analogous to Result 6 does not carry through in the case when the level of $\bar{F}$ is uncertain and signal ξ informs the retailers about its probability distribution (i.e., retailers use signal ξ updated distribution $R_{\bar{F}}(\tilde{F} \mid \xi)$ when they form their expectation about the price premium at time 3). The reason for that lies in the fact that function $\phi(\tilde{F}) = \max[\min[J(\bar{x},\theta) - 1,0],-\tilde{F}]$ (see Result 6) is convex in $\tilde{F}$ while $\min[c_S + \phi(\tilde{F}),0]$ is concave in $\phi(\tilde{F})$ (see Eqn (57)).

In this section, we investigated several consequences that a vague or unclear penalty and uncertain segregation costs may have on production decisions made by the food processors and growers. We also identified several conditions when less certain information available to growers causes them to sow more acres to variety N. It can be argued that, on average, a higher share of variety N at harvest reduces the probability that all of variety N will be processed separately (see time 2 equilibrium conditions 39). Typically, the acreage allocation response and the subsequent investment in the segregation practices are related.

Imagine that an increase in uncertainty faced by the farmers at planting raises the acreage sown to variety N. Then a government policy encouraging investment in the IP program at the harvest time may be warranted. When multiple equilibria exist, i.e., market can support different shares of the IP variety N, a government may attempt to achieve market equilibrium with the highest share of the IP variety N. It was shown that, keeping everything else equal, a higher share of the IP variety N leads to a reduction in the share of ("ex-ante") false labels. Therefore, the effect of a reduction in information available at planting or harvest appears to be relevant when designing a labeling policy.

Conclusions

This paper presents a model of a two-stage production process where the acreage allocation and the level of segregation between non-GMO and GMO varieties are sequentially determined. It is conjectured that production and marketing responses are largely driven by the volatile consumer preferences between the two food varieties. This creates incentives for the producers to falsely label a food item that is in high demand. The expected price premium paid for non-GMO labeled foods can either rise or fall when the share of non-GMO variety processed separately increases. Additionally, a higher penalty or lower IP costs affect the level of segregation not only directly (through equilibrium condition at harvest) but also indirectly (through the acreage allocation established at planting). These two effects may work in the opposite directions.

Therefore, there are two reasons why a governmental policy aimed to reduce the probability of false labeling through an increase in the expected penalty or a rebate on the IP costs may not be successful. On the one hand, if the expected price premium is a locally increasing function of the level of segregation then the intended effects of raising the penalty or subsidizing the IP costs may be reversed. On the other hand, this may happen when the direct effect on the level of segregation is dominated by the indirect effect caused by the acreage allocation response. However, the likelihood of the policy's success can be improved if any such policy is coupled with a program forcing the market to a higher level of segregation (that can be sustained by the market).

Our analysis can be extended in a number of ways. For example, we assumed away any strategic behavior that consumers may find optimal to engage in before making final consumption decisions. We also overlooked any demand expansion or substitution effects that a cheaper GMO food variety is likely to entail. In addition, this model emphases the role of consumer preferences in producers' decisions at the expense of somewhat oversimplifying the production environment. Namely, the complex infrastructure of marketing channels is completely left out of the model and the unit segregation costs are taken to be constant. A model specifying the micro foundations of segregation technologies is likely to provide further interesting insights and useful policy implications.

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Appendix A

LEMMA 1. $\partial\{(L^* - S)/L^*\}/\partial S \geq 0 \quad \forall S \in [0, x), \ \forall \theta \in [0,1]$.

PROOF: Differentiating the right-most equation in (11a), we have:

$$\frac{\partial L^*}{\partial S} = \frac{1 - J(L^*, \theta)}{S \cdot J_L(L^*, \theta) + \overline{F}}.$$

Using this, we can write:

$$\frac{\partial (S/L^*)}{\partial S} = \frac{1}{(L^*)^2}\left(L^* - S\frac{1 - J(L^*, \theta)}{S \cdot J_L(L^*, \theta) + \overline{F}}\right)$$

$$= \frac{1}{(L^*)^2}\frac{L^*(S \cdot J_L(L^*, \theta) + \overline{F}) - S(1 - J(L^*, \theta))}{S \cdot J_L(L^*, \theta) + \overline{F}} = \frac{1}{L^*}\frac{S \cdot J_L(L^*, \theta)}{S \cdot J_L(L^*, \theta) + \overline{F}} \geq 0,$$

where (11a) was used to obtain the last equality.

LEMMA 2. $\partial\{(L^* - S(\overline{F}))/L^*\}/\partial\overline{F} \geq (<) 0$ as $\partial S(\overline{F})/\partial\overline{F} < (\geq)(-1)/J_L(L^*, \theta)$, $\forall \theta \in [0,1]$.

PROOF: Differentiating the equilibrium share of false labels at time 3 with respect to $\overline{F}$, we have:

(A1) $$\frac{\partial(1 - S/L^*)}{\partial S} = -\frac{([\partial S/\partial\overline{F}]L^* - S[\partial L^*/\partial\overline{F}])}{(L^*)^2}.$$

From the right-most equation in (11a) we know that:

(A2) $$\frac{\partial L^*}{\partial\overline{F}} = \frac{[\partial S/\partial\overline{F}](1 - J(L^*, \theta)) - L^*}{S \cdot J_L(L^*, \theta) + \overline{F}}.$$

Substituting (A2) in (A1), we can write:

$$\frac{\partial(1 - S/L^*)}{\partial S} = -\frac{([\partial S/\partial\overline{F}]L^*(S \cdot J_L(L^*, \theta) + \overline{F}) - S([\partial S/\partial\overline{F}](1 - J(L^*, \theta)) - L^*)}{(L^*)^2(S \cdot J_L(L^*, \theta) + \overline{F})}.$$

Using Eqn (11a) yields:

$$\frac{\partial(1 - S/L^*)}{\partial S} = -\frac{([\partial S/\partial\overline{F}]L^*(S \cdot J_L(L^*, \theta) + \overline{F}) - ([\partial S/\partial\overline{F}]L^*\overline{F} - SL^*)}{(L^*)^2(S \cdot J_L(L^*, \theta) + \overline{F})}$$

$$= -\frac{[\partial S/\partial\overline{F}]J_L(L^*, \theta) + 1}{L^*(J_L(L^*, \theta) + \overline{F}/S)}.$$

RESULT 2. Assume that (i) $1-J(1-(1-x)\overline{F}/c_S)\geq\overline{F}$ and that the "partial segregation" equilibrium, $S^*=1-\overline{F}(1-x)/c_S\in(0,x)$, prevails at time 2, and (ii) the share of variety N supplied at harvest, x, is taken as given. Then we have:

a) if $J_L(L^*)\geq c_S/(1-x)$, where L^* is given by Eqn (7a) then $\partial\{(L^*-S^*)/L^*\}/\partial\overline{F}\geq 0$;

b) $\partial\{(L^*-S^*)/L^*\}/\partial c_S\leq 0$.

PROOF: a) Under assumption (i) equilibrium condition (18b) becomes:

(A3) $\qquad\overline{F}(1-x)/(1-S^*)=c_S$.

From (A3) the equilibrium level of segregation is then given by:

(A4) $\qquad S^*=1-\overline{F}(1-x)/c_S\in(0,x)$.

Given assumption (ii), observe that we always have $\partial S^*/\partial\overline{F}=-(1-x)/c_S<0$. Applying lemma 2 with the derivative restriction in part (a) completes the proof.[66]

b) Proceeding in a similar manner, it is clear from (A4) that $\partial S^*/\partial c_S=(1-x)\overline{F}/c_S^2>0$. Apply lemma 1 to prove part (b).

RESULT 5. If $R_\theta(\theta\mid\xi)$ is decreasing and convex in $\xi\in[\underline{\xi},\overline{\xi}]$ for each $\theta\in[0,1]$ then an upper bound on equilibrium acreage allocated to variety N decreases under a SSD shift $R_\xi(\xi)\to R_\xi^1(\xi)$.

PROOF: The proof is follows immediately from two observations. First, the function $\min[c_S+\phi,0]$ is concave and increasing in ϕ. If the signal-conditioned expectation at time 2 is concave in ξ then the function $\min[c_S+E_2[.\mid\xi],0]$ is concave in ξ as well, because the property 'increasing and concave' is preserved under composition. Second, we show that the time 2 expectation is increasing and concave in ξ when $R_\theta(\theta\mid\xi)$ is decreasing and convex in ζ. Note that we can write:

$$E[\phi(\theta)\mid\xi]=\int_0^{\hat{\theta}}\phi(\theta)dR_\theta(\theta\mid\xi)-\int_{\hat{\theta}}^1\phi(\theta)d\overline{R_\theta}(\theta\mid\xi),$$

[66] The local derivative condition in part (a) of result 2 is both necessary and sufficient for the result to hold. A slightly simpler sufficient condition of the form $J_L(L)\geq c_S/(1-x)\quad\forall L\in[S,1]$ can be used.

where $\overline{R_\theta}(\theta \mid \xi) = 1 - R_\theta(\theta \mid \xi)$ and $\hat{\theta} \in (0,1)$.

Apply an integration by parts to obtain:

$$E[\phi(\theta) \mid \xi] = \phi(\hat{\theta})R_\theta(\hat{\theta} \mid \xi) - \int_0^{\hat{\theta}} \phi'(\theta)R_\theta(\theta \mid \xi)d\theta + \phi(\hat{\theta})\overline{R_\theta}(\hat{\theta} \mid \xi) + \int_{\hat{\theta}}^1 \phi'(\theta)\overline{R_\theta}(\theta \mid \xi)d\theta$$

$$= \phi(\hat{\theta}) - \int_0^{\hat{\theta}} \phi'(\theta)R_\theta(\theta \mid \xi)d\theta + \int_{\hat{\theta}}^1 \phi'(\theta)\overline{R_\theta}(\theta \mid \xi)d\theta .$$

Assume that $\phi'(\theta) \geq 0 \;\; \forall\, \theta \in [0,1]$. Now it is immediate that $E_\xi[\phi(\theta) \mid \xi]$ and $E_{\xi\xi}[\phi(\theta) \mid \xi]$, where the subscripts denote differentiation, inherit the opposite of the sign of $\partial R_\theta(\theta \mid \xi)/\partial\xi$ and $\partial^2 R_\theta(\theta \mid \xi)/\partial\xi^2$, respectively. In our case, we have $\phi(\theta) = \max[\min[J(\bar{x},\theta) - 1,0],-\overline{F}]$ which is increasing in θ. We can overlook the fact that this function may not be differentiable everywhere once we observe that $\phi'(\theta)$ only appears under the sign of integration. Apart from this technical difficulty, the proof is complete.[67]

Appendix B

Observe from Eqn (38) in the text that the direct effects dominate when

(B1) $\quad \partial x^* / \partial c_S \geq -G_{c_S} / G_x$ and $\partial x^* / \partial \overline{F} \leq -G_{\overline{F}} / G_x$.

Rewrite function $G(S,x,c_S,\overline{F},\xi)$ as follows:

$$G \equiv \frac{1-x}{1-S}\left[\int_{\theta_1}^{\theta_2} (1 - J(S,\theta))dR(\theta \mid \xi) + \overline{F}R(\theta_1 \mid \xi)\right] - c_S,$$

where $\theta_1 = \max[\theta_1', \underline{\theta}]$, $\theta_2 = \min[\theta_2', \overline{\theta}]$, $\theta_1' = \inf_\theta\{\theta : 1 - J(S,\theta) = \overline{F}\}$ and $\theta_2' = \inf_\theta\{\theta : 1 - J(S,\theta) = 0\}$.

Differentiating function $G(S,x,c_S,\overline{F},\xi)$ with respect to x, $\overline{F}$, and c_S, we have:

$$G_x = \frac{-1}{1-S}\left[\int_{\theta_1}^{\theta_2} (1 - J(S,\theta))dR(\theta \mid \xi) + \overline{F}R(\theta_1 \mid \xi)\right],$$

$$G_{\overline{F}} = \frac{1-x}{1-S}R(\theta_1 \mid \xi).$$

$$G_{c_S} = -1.$$

Substitute these in (B1) to obtain the following conditions guaranteeing that the direct effect, G_k, dominates the indirect effect, $G_x[\partial x^* / \partial k]$, where $k = c_S, \overline{F}$:

[67] In fact, Result 2 follows directly from Theorem 6.C.1 in Shaked and Shanthikumar (1994, p.186)

$$\frac{\partial x^*}{\partial c_s} \geq -(1-S^*)/[\int_{\theta_1}^{\theta_2}(1-J(S^*,\theta))dR(\theta \mid \xi)+\overline{F}R(\theta_1 \mid \xi)]$$

$$\frac{\partial x^*}{\partial \overline{F}} \leq (1-x^*)R(\theta_1 \mid \xi)/[\int_{\theta_1}^{\theta_2}(1-J(S^*,\theta))dR(\theta \mid \xi)+\overline{F}R(\theta_1 \mid \xi)].$$

CHAPTER 6. GENERAL SUMMARY

In this thesis several analytical techniques have been applied to solve problems in agricultural finance and in the microeconomics of demand-driven biotechnology adoption. In Chapter 2 (Paper I) we found necessary and sufficient conditions ensuring that net present value is monotone in the discount rate. We also identified a simple sufficient condition on projects' cash flows that can be used to unambiguously order projects by the internal rate of return statistic. This paper provides an example of the application of mathematical order concepts to problems in finance theory.

In Chapter 3 (Paper II) we investigated the relationship between rental rates sensitivity to output price and land quality from both the theoretical and empirical perspectives. We proposed and applied an estimation technique to deal with the main econometric difficulty arising in the empirical part of the analysis: the two-dimensional autocorrelation among the disturbances. Explicitly accounting for many important features characteristic of farmland leasing contracts such as infrequency of renegotiation, possible land market frictions, government payments, and risk-aversion may well be worthy of further inquiry.

In Chapter 4 (Paper III) we used a product differentiation model to investigate the hypothesis that the drop in the U.S. acreage sown to GM crop varieties in 2000 can be attributed to the scarcity of information on consumers' attitudes towards biotechnology witnessed at planting. Borrowing from the emerging literature on the value of information, we also characterized the types of signals that growers are likely to find valuable in guiding their planting decisions. One of the limiting assumptions that significantly simplified the analysis is that consumers costlessly differentiate between non-GMO and GMO varieties.

This assumption is relaxed in Chapter 5 (Paper IV) that generalizes the framework of Paper III and adds a production stage where the segregation between the two varieties takes place. We show that a governmental policy to suppress false labeling by means of a harsher fine, improved inspection, or rebate on the segregation costs is likely to be more successful if administered jointly with a program forcing the market to a higher level of segregation. The workhorse of our approach - the model of product differentiation – appears to be an insightful way of studying the issues related to adoption of biotechnology in agriculture and can probably be of further use to economists.

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