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Planting Decisions and Uncertain Consumer Acceptance of Genetically Modified Crop Varieties

by

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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 the extent of demand uncertainty to determine equilibrium varietal plantings and the probability that post-harvest varietal prices will differ. Also, as planting approaches signals will be received by growers about the nature of demand they will be planting into. We show how the non-linearity affects the order on the types of signals that risk-neutral growers will prefer to receive.

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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

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[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.

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

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[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.

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

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[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.

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

[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.

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

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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.

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]

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[9] See Value Line (2000). Monsanto's *Roundup*® (glyphosate) is a contact herbicide. Patents on it, and owned by Monsanto, began to expire in 1999. Seed with built-in glyphosate tolerance comprised one of the best-selling lines of GM seeds, and stimulated demand for *Roundup*®. Monsanto also owned patents on technologies behind glyphosate tolerant seed.

[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.

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.

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

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 $U(0, 1) \equiv \epsilon \in [0, 1]$. 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 $\epsilon = 1$.

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 $\epsilon - p_g \geq 1 - p_n$ while she chooses NM otherwise. The threshold type is given by $\epsilon^* = 1 + p_g - p_n$, and the cumulative mass distribution of types is given by $H(\epsilon \mid \theta)$. 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 $H(\epsilon \mid \theta)$ is defined on $[0, \epsilon^{+}(\theta)]$ where $\epsilon^{+}(\theta)$ solves $H(\epsilon^{+}(\theta) \mid \theta) = 1$. But, as will become apparent, values on $(1, \epsilon^{+}(\theta)]$ have little in the way of economic relevance. As illustrated in Figure 2, we assume that $H(\epsilon \mid \theta)$ has value 0 on $[0, h_0(\theta))$, is strictly increasing on $[h_0(\theta), 1]$, 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.

Now define the correspondence $T(\epsilon, \theta) = H(\epsilon \mid \theta)$ on $\epsilon \in [h_0(\theta), 1)$ and $T(\epsilon, \theta) = [H_1(\theta), 1]$ on $\epsilon = 1$. 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 $T(\epsilon, \theta)$. 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 $z \in T(\epsilon, \theta)$, this inverse function is given by $H^{-1}(z \mid \theta) = \; J(z \mid \theta)$ on $[0, H_1(\theta))$ and 1 on $z \in [H_1(\theta), 1]$. The inverse function is given by traversing up $H(\epsilon \mid \theta)$ to $H_1(\theta)$, and then piecing on the flat section $\epsilon = 1$ 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

[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 $\mathrm{Min}[J(z \mid \theta) - 1, 0]$ is increasing in θ. This latter function will be countenanced shortly.

must decrease demand for the NM variety.

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

$$x \in T(\epsilon^* \mid \theta), \tag{1}$$

with correspondence inversion

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

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

13 Please see footnote 4 above.

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

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

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

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

where the $\mathrm{Min}[\cdot, \cdot]$ 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 $J(x \mid \theta) = 1$. This set depends on acreage allocation, and

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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.

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 $c_n - c_g + \int_0^1 \mathrm{Min}[J(x \mid \theta) - 1, 0]\, dR(\theta)$, where the pertinent argument of the $\mathrm{Min}[\cdot,\cdot]$ 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 $R(\hat{\theta})$, in which case a decision to grow the NM variety turns out to have been a bad bet.

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

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

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^*.

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[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 $\hat{\theta}(x)$ 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.

Effects of Uncertainty

The function $\text{Min}[J-1,0]$ is increasing and concave in J. Further, the property 'increasing and concave' is preserved under composition.[17] And so, if $J_{\theta\theta}(x \mid \theta) \leq 0$ 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* $J_{\theta\theta}(x \mid \theta) \leq 0\ \forall\, \theta \in [0,1],\ \forall\, x \in (0,1]$. *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 $H(\epsilon \mid \theta) = H(\epsilon - \theta)$ so that $\epsilon^* - \theta = 1 + p_g - p_n - \theta = Y(x)$ where relation (2) requires that $Y(x) = J(x \mid \theta) - \theta$. Now we can write Eqn. (5) as

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[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 $R(\theta)$.

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

and the Proposition holds because of the linearity of $J(x \mid \theta)$ 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 $\int_0^{1 - Y(x_r^*)} R(\theta)\, d\theta \geq \int_0^{1 - Y(x_r^*)} R_1(\theta)\, d\theta$. And so it is required that $\int_{1 - Y(x_{r1}^*)}^{1 - Y(x_r^*)} R_1(\theta)\, d\theta \leq 0$, i.e., that $x_r^* \geq x_{r1}^*$.

Notice that assumption $J_{\theta\theta}(x \mid \theta) \leq 0$ 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 $J_{\theta\theta}(x \mid \theta) \leq 0$ 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 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 $R^1(\theta) \overset{ssd}{\geq} R(\theta)$. 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; $\theta \rightarrow \theta + bk(\theta)$ where $b \geq 0$ 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 $\theta \to \theta + b\,k(\theta)$ on $\hat\theta$ depends on a single evaluation of the map, namely $\hat\theta + b\,k(\hat\theta)$. 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

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

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

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

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 $\zeta \in \mathbf{Z}$, and the ex-ante joint distribution of the random variables is $F(\zeta, \theta): \mathbf{Z} \times [0, 1] \to [0, 1]$. 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 $F_{\mathbf{Z}}(\zeta \mid \theta)$ 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 $\hat{F}(\zeta, \theta): Z \times [0, 1] \to [0, 1]$ 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

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[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.

$F_\Theta(\theta \mid F_Z(\zeta) \geq t)$. To interpret this function, first choose some $t \in [0, 1]$. Then identify the set of signals $\zeta \in \mathbf{Z}$ from the marginal distribution of signals $F_Z(\zeta)$ such that $F_Z(\zeta) \geq t$. For concreteness, let $\mathbf{Z} = [0, 1]$ 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

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

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

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[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.

PROPOSITION 3. *Suppose that* $J_{\theta\theta}(x \mid \theta) \le 0$. *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 $\overset{ssd}{\ge}$ relation in the lower line of the MIO ordering. Over the same set of high-end percentile (i.e., $\zeta \in [F_{\mathbf{Z}}^{-1}(t), 1]$) 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 $J_{\theta}(x \mid \theta) \ge 0$ 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]

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[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.

PROPOSITION 4. *Suppose that* $J_{\theta\theta}(x \mid \theta) \le 0$. *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

[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).

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.

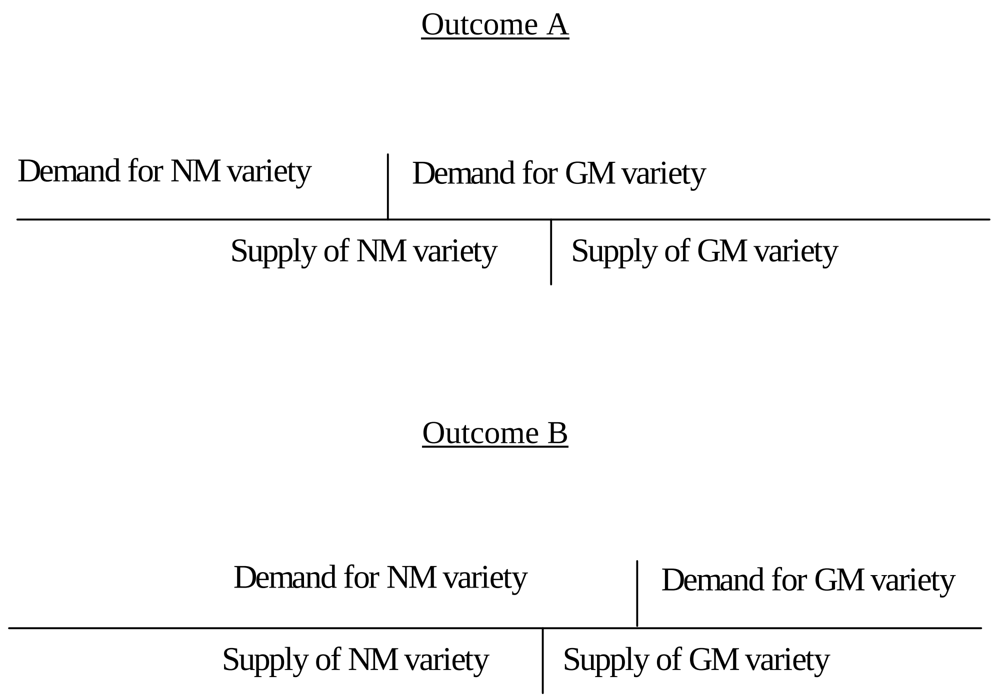

Figure 1. Asymmetry in arbitrage opportunities across varieties

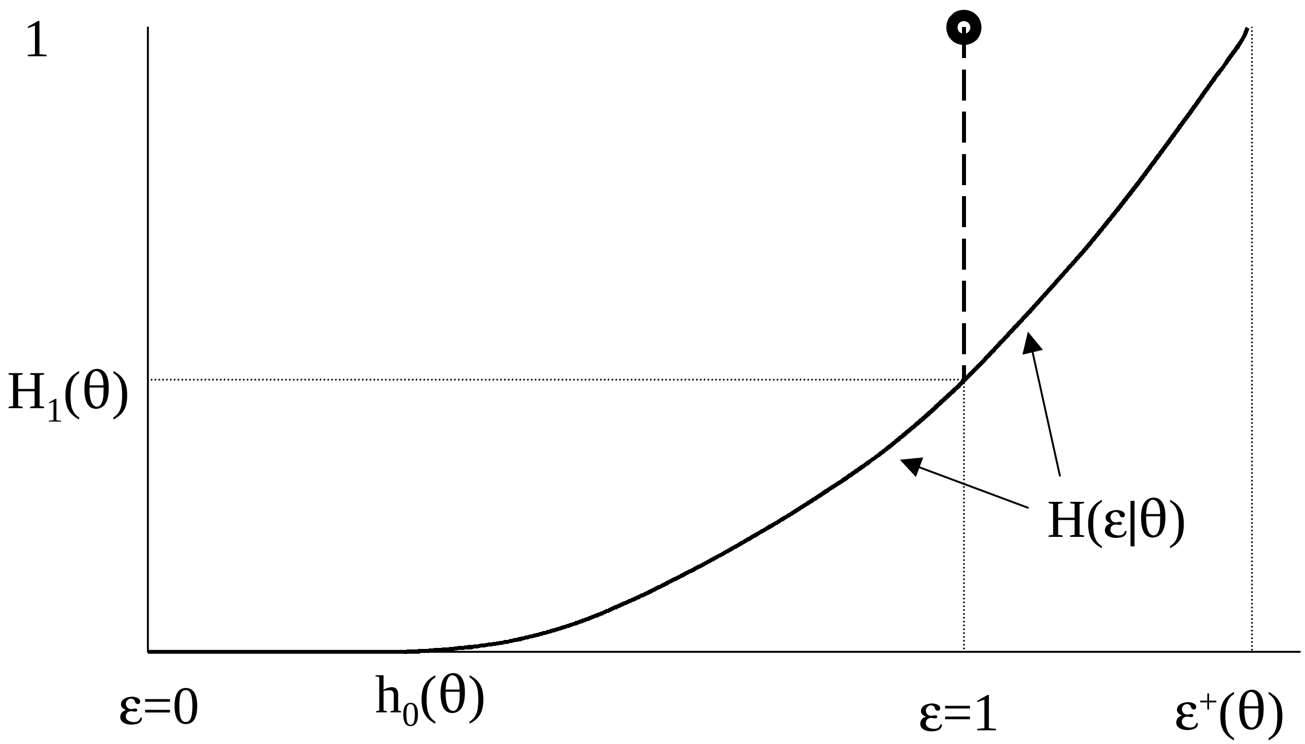

Figure 2. Distribution of preferences for NM varieties