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The Market Potential of a New High-Oleic Soybean: An Ex Ante Analysis

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This paper develops a model of heterogeneous consumer preferences to analyze the market potential of a second-generation, genetically modified, high-oleic soybean developed at the University of Nebraska. The paper identifies the factors that will determine the effectiveness of the new technology and the implications for domestic producer welfare if the new technology were licensed exclusively to producers in the United States. Analytical results show that the market and welfare effects of the introduction of high-oleic soybeans are determined by the relative prices of products utilizing the new soybeans as an input in their production process, the distribution of consumer preferences, and the benefits consumers perceive from the new product. The lower the prices of products using the new soybeans and/or the greater the value consumers place on the new product attribute, the greater the market acceptance of the new high-oleic soybeans, the market share of the United States in the world market for soybeans, and the domestic producer welfare gains from the introduction of the new technology. When the value consumers place on the new product attribute is sufficiently high, the introduction of high-oleic soybeans is shown to drive the conventional soybeans out of the market, attract consumers of substitute products, and confer considerable benefits to all domestic soybean producers.

Keywords: agricultural biotechnology, genetically modified products, high-oleic soybeans

The introduction of genetically modified (GM) products into the food system has been a highly contentious issue eliciting divergent responses from major players of the agri-food sector. Although farmers have been embracing the agronomic benefits associated with the first generation of producer-oriented GM products (James, 2003), an increasing number of consumers have been raising objections to food containing GM ingredients in major markets around the world. Consumer reaction to GM products is founded on health, environmental, and ethical or philosophical concerns (Caswell, 1998; Giannakas & Fulton, 2002; Hobbs & Plunkett, 1999) and has impaired the potential of agricultural biotechnology.

As a response, life science companies and researchers in academia have been focusing their efforts on the development of consumer-oriented, second-generation GM products with augmented functional properties. (For examples of biotechnology quality traits in major agricultural crops, see Kalaitzandonakes & Maltsbarger, 2004.) A case in point is a new soybean developed by the soybean biotechnology team at the University of Nebraska. When compared to conventional soybeans, the new germplasm is high in oleic acid (>85%), which translates into increased quality of oil derived from the crop (Buhr et al., 2002).

An objective of this paper is to systematically analyze the market potential of this new high-oleic soybean. The paper focuses on the market and welfare effects of the introduction of the new soybean and seeks to identify the factors that will determine the effectiveness of the new technology as well as the implications for domestic producer welfare if this technology were licensed exclusively to US producers. The study builds on the work by Giannakas and Yiannaka (2003) that develops a general framework for analyzing the market and welfare effects of the introduction of consumer-oriented GM products.

In analyzing the market and welfare effects of the introduction of the new high-oleic soybean, this paper explicitly accounts for differences in consumer preferences for different products. Consumer heterogeneity, in terms of preferences for different products, is a key component in our model, and it is critical in explaining the coexistence of markets for products with different characteristics. Although the analysis of consumer behavior focuses on the market for oil, the results have implications for all products utilizing soybeans as an input in their production process (e.g., animal feed and biodiesel).

The rest of the paper is organized as follows. The next section presents a simple model of heterogeneous consumer preferences. The sections following analyze consumer purchasing decisions before and after the introduction of the new high-oleic soybean. The implications of the introduction of the new soybeans for domestic producer welfare are considered before the final section summarizes and concludes the paper.

Benchmark Case: Status Quo in the World Oil Market

Product and Consumer Characteristics

There are currently a number of oils of different qualities supplied in the world market. In terms of their market shares during 2002/03, soybean and palm oils enjoyed the greatest shares of the world market (30.54% and 27.21%, respectively), followed by canola (11.78%), sunflower seed (8.37%), peanut (4.34%), cottonseed (3.49%), coconut (3.17%), and olive oil (2.16%; United States Department of Agriculture [USDA], 2004). Although there are many characteristics that differentiate these products, the analysis focuses on their differences in oleic and *trans* fatty acids. The greater the oleic acid content of an oil and/or the lower its level of *trans* fatty acids, the greater the perceived quality of the product. Given the focus of the analysis on soybean oil, we will group and term the substitute oils with inferior quality attributes (i.e., oils with low oleic acid and/or high *trans* fatty acids, such as various tropical oils) as *low-quality oil* and the substitute oils with superior quality attributes (i.e., oils with high oleic acid and/or low *trans* fatty acids such as canola, sunflower, and olive oil) as *high-quality oil*.

In this context, the different oils are treated by consumers as *vertically differentiated products* (Mussa & Rosen, 1978)—if offered at the same price, all consumers exhibiting a preference for the oleic acid and/or the *trans* fatty acids would prefer the high-quality product. On the other hand, if only the soy oil and the low-quality oils were available and priced the same, consumers would buy the soy oil. Although the different products are, by definition, uniformly quality ranked by consumers who value the specific attributes of these products, consumers differ in their willingness to pay for the perceived quality differences between the different oils. Note that for simplicity and without loss of generality, the analysis treats soy oil derived from first-generation GM crops and soy oil derived from non-GM soybeans as a single good. Although oil derived from the two crops might differ in the eyes of the consumer, soybeans are generally not segregated and are marketed together as a nonlabeled good. In this context, our conventional soy oil can be seen as being produced by nonlabeled GM and non-GM soybeans.

To capture these elements, consider a consumer that consumes one unit of either a high-quality oil, the conventional soy oil, or a low-quality oil; the purchasing decision represents a small share of her total budget. Her utility function can be written as

$U_L = U - p_L - \alpha c$ if a unit of low-quality oil is consumed,

$U_S = U - p_S - \beta c$ if a unit of conventional soy oil is consumed, and

$U_H = U - p_H + \gamma c$ if a unit of high-quality oil is consumed,

where U_L, U_S, and U_H are the utility associated with the unit consumption of low-quality oil, soy oil, and high-quality oil, respectively. The terms p_L, p_S, and p_H denote the equilibrium prices of the three oils. The parameter U is a base level of utility derived from the consumption of oil and is constant across consumers. The terms α and β are non-negative utility discount factors associated with the consumption of low-quality oil and soy oil, respectively, while γ is a non-negative utility enhancement factor associated with the consumption of high-quality oil. The parameter c takes values between zero and one and differs according to consumer capturing heterogeneous consumer preferences (and thus, heterogeneous willingness to pay) for the three products.[1]

Specifically, the characteristic c can be seen as capturing differences in consumer preferences with regards to the levels of oleic and *trans* fatty acids in the three oils. The greater c is, the greater the consumer aversion to (and the discount in utility from the consumption of) oils with low oleic acid and/or high *trans* fatty acids and the greater the utility derived from oil with high oleic acid. Thus, for a consumer with attribute c, the terms αc and βc give the utility discount from consuming the low-quality oil and soy oil, respectively, whereas the term γc is the utility enhancement from consuming the high-quality oil.[2]

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1. *Consumers with a c value of zero would be indifferent between the different oils if those were offered at the same price.*

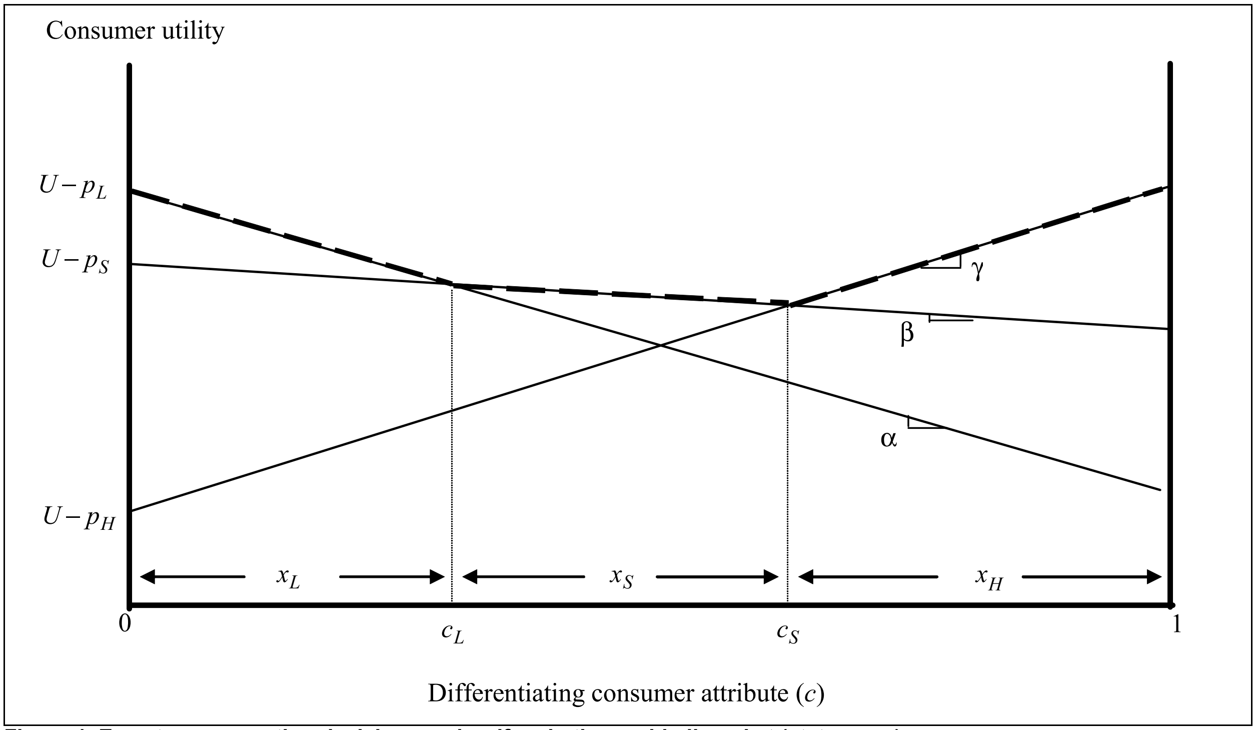

Figure 1. Ex ante consumption decisions and welfare in the world oil market (status quo).

To capture the empirically relevant case where the different products enjoy positive shares of the market, we assume that $\alpha > \beta$ (see below). For tractability, the analysis assumes that consumers are uniformly distributed between the polar values of c. The implications of relaxing this assumption are straightforward and are discussed throughout the text.

Consumer Purchasing Decisions and Demands for the Different Oils

A consumer's purchasing decision is determined by comparing the utilities derived from the three products. Figure 1 illustrates the decisions and welfare of consumers for the empirically relevant case where $p_L < p_S < p_H$ and the consumer preferences are such that all three products enjoy positive market shares.[3] The upward-sloping curve graphs utility levels when the high-quality oil is purchased; the downward-sloping lines show the utilities when the low-quality oil and the conventional soy oil are purchased for different levels of the differentiating attribute c.

The intersection of the utility curves U_L and U_S determines the level of the differentiating attribute that corresponds to the consumer who is indifferent between the low-quality oil and the soy oil while the intersection of the utility curves U_S and U_H determines the level of c that corresponds to the consumer who is indifferent between the soy oil and the high-quality oil. Formally, the consumer with differentiating characteristic c_L, given by

$$c_L : U_L = U_S \Rightarrow c_L = \frac{p_S - p_L}{\alpha - \beta}, \quad (1)$$

is indifferent between consuming a unit of the low-quality oil and a unit of the conventional soy oil; the consumer with differentiating characteristic c_S, given by

$$c_S : U_S = U_H \Rightarrow c_S = \frac{p_H - p_S}{\beta + \gamma}, \quad (2)$$

2. *In this context, $U - \alpha c$, $U - \beta c$ and $U + \gamma c$ represent the consumer willingness to pay (WTP) for a unit of the low-quality oil, the conventional soy oil, and the high-quality oil, respectively. Subtracting the relevant prices from these WTP values provides an estimate of the consumer surplus associated with the consumption of these products.*

3. *Note that the three products are not priced the same. Given the vertical differentiation of the three products and their uniform quality ranking by consumers, for any positive quantity of low-quality oil to be demanded, p_L should be less than p_S. Similarly, for any positive quantity of conventional soy oil to be demanded, p_S should be less than p_H.*

is indifferent between soy oil and the high-quality oil. Consumers "located" to the left of c_L (i.e., consumers with $c \in [0, c_L)$) purchase the low-quality oil, while those located to the right of c_L (i.e., consumers with $c \in (c_L, 1]$) buy either the conventional soy oil (consumers with $c \in (c_L, c_S]$) or the high-quality oil $c \in (c_S, 1]$). Aggregate consumer welfare is given by the area underneath the effective utility curve shown as the (bold dashed) kinked curve in Figure 1.

When consumers are uniformly distributed with respect to their differentiating attribute c, the level of c corresponding to the indifferent consumer, c_L, also determines the market share of the low quality product. The market shares of soy oil and the high-quality oil are given by $c_S - c_L$ and $1 - c_S$, respectively. By normalizing the mass of consumers at unity, the market shares give the consumer demands for the low-quality oil (x_L), the soy oil (x_S), and the high-quality oil (x_H). In what follows, the terms *market share* and *demand* are used interchangeably to denote x_L, x_S, and/or x_H. Formally, x_L, x_S, and x_H can be written as

$$x_L = \frac{p_S - p_L}{\alpha - \beta}, \tag{3}$$

$$x_S = \frac{(\alpha - \beta)p_H + (\beta + \gamma)p_L - (\alpha + \gamma)p_S}{(\alpha - \beta)(\beta + \gamma)}, \text{ and} \tag{4}$$

$$x_H = \frac{\beta + \gamma - (p_H - p_S)}{\beta + \gamma}. \tag{5}$$

The preceding analysis indicates that the market shares of the three products are determined by the consumer attitudes towards oleic and *trans* fatty acids and their relative prices. The market share of soy oil increases with an increase in the price of its substitutes (i.e., low- and high-quality oils) and the preference parameter α, and falls with an increase in its own price and/or an increase in the preference parameters β and γ.

The analysis can be easily modified to examine cases where consumers are not uniformly distributed with respect to their value of c. When the distribution of consumers is continuous (but not uniform), consumer demand for the different products depends on its skewness. For instance, the more skewed is the distribution towards 1, the greater is the market share of, and the demand for, the high-quality oil.

Ramifications of the Introduction of High-Oleic Soy Oil

Consider now the case where a new soy oil is introduced into the market. Relative to the conventional soy oil, the new soy oil is derived from genetically engineered soybeans containing high oleic acid. With the introduction of the new high-oleic soy oil there are four goods in the market—the high-oleic soy oil, the conventional soy oil, the low-quality oil, and the high-quality oil—and the consumer utility function becomes

$U_L = U - p_L - \alpha c$ if a unit of low-quality oil is consumed,

$U_S = U - p_S - \beta c$ if a unit of conventional soy oil is consumed,

$U_H = U - p_H + \gamma c$ if a unit of high-quality oil is consumed, and

$U_S^N = U - p_S^N + \kappa c$ if a unit of new high-oleic soy oil is consumed,

where U_S^N is the utility associated with the unit consumption of the high-oleic soy oil and p_S^N is the price of the new product. The parameter κ is the utility enhancement factor associated with the unit consumption of high-oleic soy oil and captures the value different consumers place on the new product attribute.[4] The greater is κ, the greater is the value consumers place on high oleic content, and the greater is the utility derived from the consumption of the high-oleic soy oil. All other variables are as previously defined.

The market effects of the introduction of the high-oleic soy oil are shown to depend on the price of the new product, p_S^N (which is determined by the structure of its supply channel and the segregation costs required in keeping the new product separate from the conventional one[5]), the distribution of consumer preferences, and the value consumers place on the new product attribute, κ. For certain values of p_S^N and κ, the product innovation turns out to be ineffective (Scenario I), drastic (Scenario II), or non-drastic (Scenario III). The next sections identify the exact conditions that give rise to each of these scenarios.

Scenario I: Ineffective Product Innovation

In this scenario, the relative prices and preference parameters are such that U_S^N is less than U_L, U_S, or U_H for all consumers (i.e., the U_S^N utility curve lies under-

4. *The value different consumers place on the increased oleic acid of the new soy oil is given by (*$\kappa + \beta$*)c.*
5. *For a thorough discussion of the issues and challenges involved in the development of a supply chain designed to preserve the identity of a new product like the high-oleic soy oil, see Darroch, Akridge, and Boehlje (2002).*

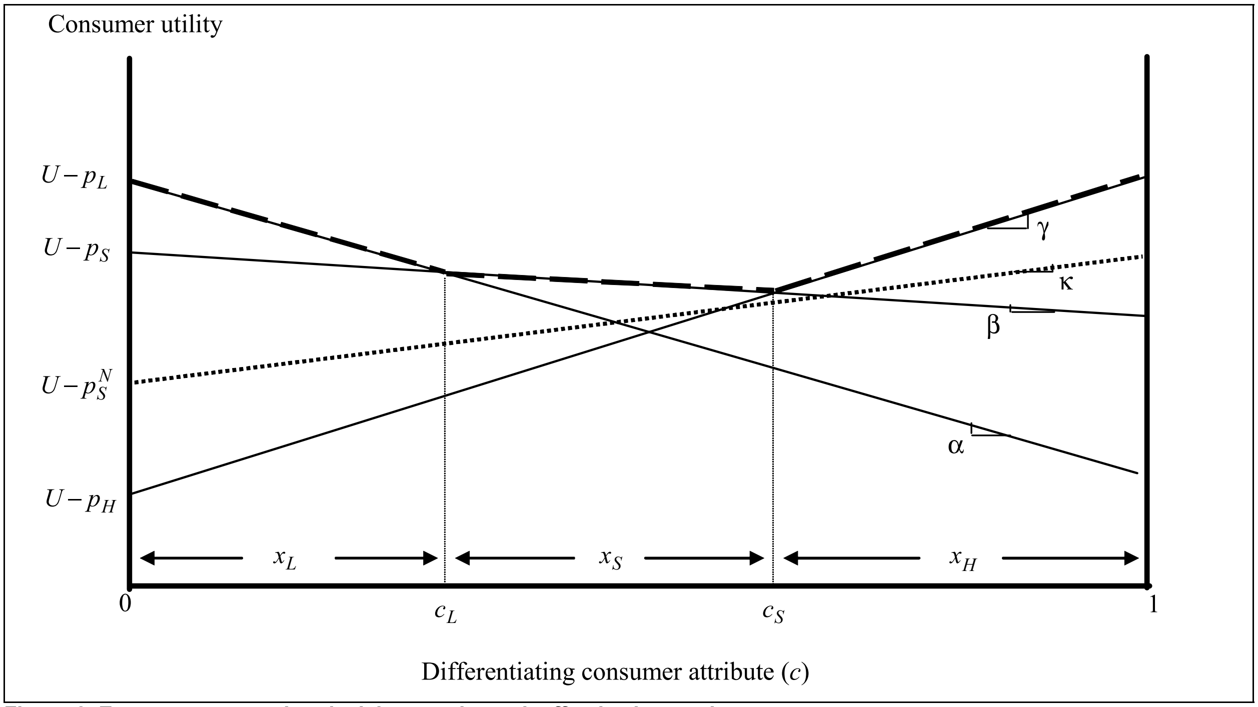

Figure 2. Ex post consumption decisions under an ineffective innovation.

neath the U_L, U_S, or U_H utility curves $\forall c$), and there is no market for the new product. The consumer demand for high-oleic soy oil, x_S^N, is zero when the new high-oleic soy oil is too expensive or when the consumer valuation of the new product attribute is relatively low. Specifically, $x_S^N = 0$ when

$$p_S^N \geq \frac{\kappa(p_H - p_S) + \beta p_H + \gamma p_S}{\beta + \gamma} \text{ or} \tag{6}$$

$$\kappa \leq \frac{(\beta + \gamma)p_S^N - \beta p_H - \gamma p_S}{p_H - p_S}.$$

In such a case, the consumption shares of (and demands for) the low-quality product, the conventional soy oil, and the high-quality product are given by Equations 3, 4, and 5, respectively. Figure 2 depicts this case.

Scenario II: Drastic Product Innovation

While a high price and a low consumer valuation make the new product innovation ineffective, relatively low prices and/or high consumer valuation of the new product attribute result in the high-oleic soy oil being a drastic product innovation, in the sense that its introduction drives the conventional soy oil out of the market. For this scenario to emerge, U_S should be less than U_S^N for all former consumers of the conventional soy oil (i.e., the utility curve U_S should lie underneath the U_S^N utility curve $\forall c \in (c_L, c_S]$, in which case x_S falls to zero). The combination of prices and preference parameters that result in the product innovation being drastic is given by

$$p_S^N \leq \frac{\kappa(p_S - p_L) + \alpha p_S - \beta p_L}{\alpha - \beta} \text{ or} \tag{7}$$

$$\kappa \geq \frac{(\alpha - \beta)p_S^N - \alpha p_S + \beta p_L}{p_S - p_L}.$$

Figure 3 graphs this case and shows that not only does a drastic product innovation drive the conventional soy oil out of the market, it can also attract consumers of both the low- and the high-quality products. In particular, if the conditions presented in Equation 7 are met, consumers with $c \in (c_L', c_L]$ and $c \in (c_S, c_S^{N'}]$ in Figure 3 find it optimal to switch their consumption from the low-quality oil and the high-quality oil, respectively, to the new high-oleic soy oil.[6] The consumer demands for the different products are then given by

$$x_L^{(D)} = \frac{p_S^N - p_L}{\kappa + \alpha}, \tag{8}$$

6. *Note that, for simplicity of exposition, Figure 3 is drawn on the assumption of free entry in the retail market of the different oils.*

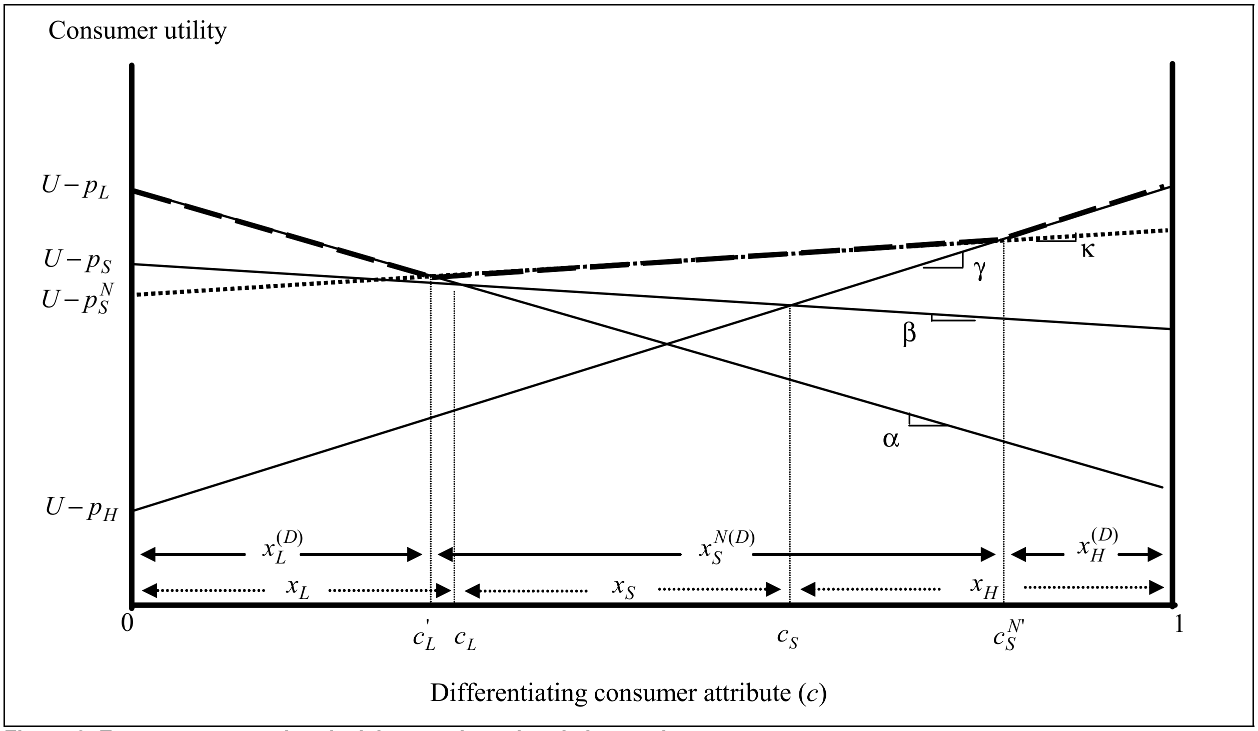

Figure 3. Ex post consumption decisions under a drastic innovation.

$$x_H^{(D)} = \frac{\gamma - \kappa - (p_H - p_S^N)}{\gamma - \kappa}, \qquad (9)$$

$$x_S^{(D)} = 0\text{, and} \qquad (10)$$

$$x_S^{N(D)} = \frac{(\kappa+\alpha)p_H + (\gamma-\kappa)p_L - (\alpha+\gamma)p_S^N}{(\gamma-\kappa)(\kappa+\alpha)}, \qquad (11)$$

where the superscript *(D)* stands for *drastic innovation*.

The previous analysis indicates that the lower is p_S^N and/or the greater is κ, the greater is the share of consumers switching to the new product. If $p_S^N \le p_H - \gamma + \kappa$ (or, equivalently if $\kappa \ge \gamma - (p_H - p_S^N)$), the high-quality product is driven out of the market (the U_H utility curve lies underneath the U_S^N utility curve $\forall c$ and $x_H^{(D)} = 0$), whereas if $p_S^N \le p_L$, the new soy oil dominates the market (the U_S^N utility curve lies above all other three utility curves $\forall c$ and $x_S^{N(D)} = 1$).

Scenario III: Effective but Nondrastic Product Innovation

After having identified the exact economic conditions that result in the new high-oleic soy oil being either an ineffective or a drastic product innovation (Scenarios I and II, respectively), we move next to the determination of the economic conditions that result in the coexistence of the conventional and the high-oleic soy oils (i.e., the conditions that result in the new soy oil being an effective but nondrastic product innovation). Because a high price and/or a low consumer valuation make the innovation ineffective (Equation 6) and a low price and/or a high consumer valuation make the innovation drastic (Equation 7), a nondrastic innovation should involve an intermediate price and/or an intermediate consumer valuation of the new product.

Indeed, the combination of prices and preference parameters that result in the product innovation being nondrastic (but effective) is given by

$$\frac{\kappa(p_S - p_L) + \alpha p_S - \beta p_L}{\alpha - \beta} < p_S^N \qquad (12)$$

$$p_S^N < \frac{\kappa(p_H - p_S) + \beta p_H + \gamma p_S}{\beta + \gamma}\text{, or}$$

$$\frac{(\beta+\gamma)p_S^N - \beta p_H - \gamma p_S}{p_H - p_S} < \kappa$$

$$\kappa < \frac{(\alpha-\beta)p_S^N - \alpha p_S + \beta p_L}{p_S - p_L}.$$

The consumer demands for the different products are then given by

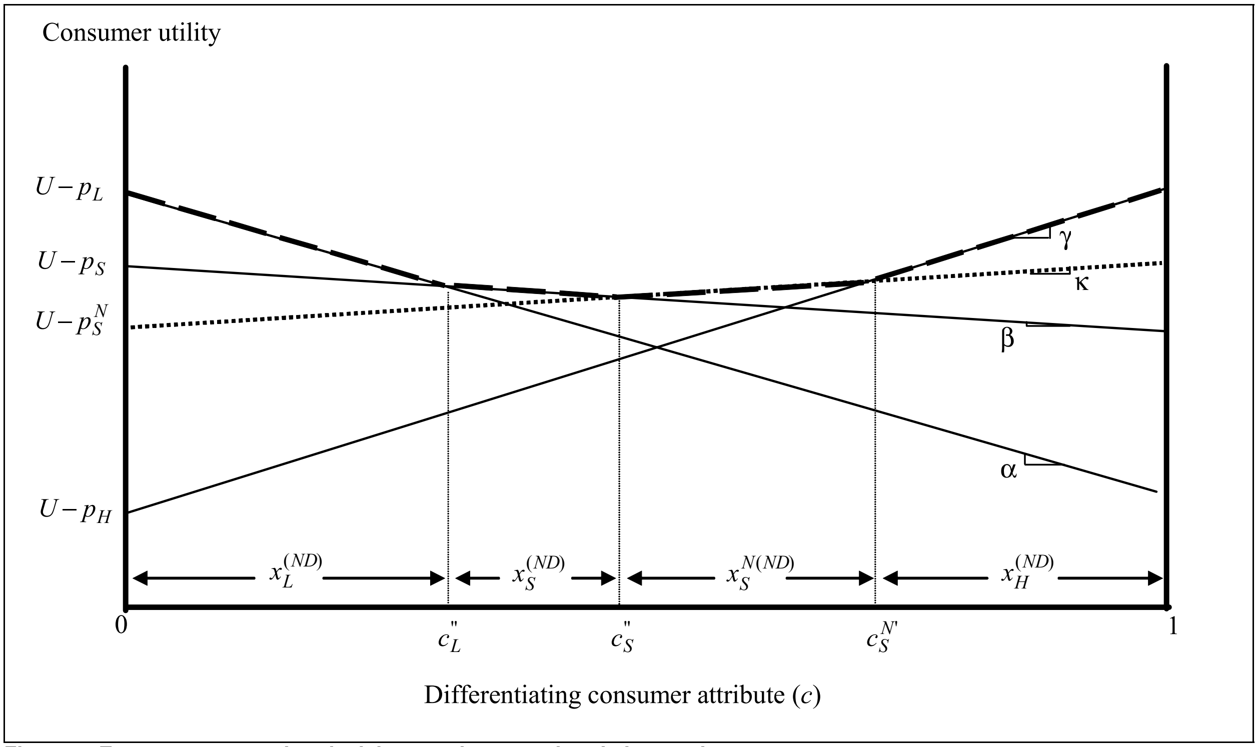

Figure 4. Ex post consumption decisions under a nondrastic innovation.

$$x_L^{(ND)} = \frac{p_S - p_L}{\alpha - \beta}, \quad (13)$$

$$x_H^{(ND)} = \frac{\gamma - \kappa - (p_H - p_S^N)}{\gamma - \kappa}, \quad (14)$$

$$x_S^{(ND)} = \frac{(\alpha - \beta)p_S^N + (\kappa + \beta)p_L - (\alpha + \kappa)p_S}{(\alpha - \beta)(\kappa + \beta)}, \text{ and } (15)$$

$$x_S^{N(ND)} = \frac{(\kappa + \beta)p_H + (\gamma - \kappa)p_S - (\beta + \gamma)p_S^N}{(\gamma - \kappa)(\kappa + \beta)}, \quad (16)$$

where the superscript *(ND)* stands for *nondrastic innovation*.

Figure 4 graphs this scenario and shows that the new high-oleic soy oil can attract consumers both from the conventional soy oil and the high-quality product. The greater the price difference $p_H - p_S^N$, the greater the share of consumers that find it optimal to switch their consumption from the high-quality oil to the high-oleic soy oil. When $p_S^N \leq p_H - \gamma + \kappa$ (or, equivalently, when $\kappa \geq \gamma - (p_H - p_S^N)$), the introduction of the new oil drives the high-quality product out of the market (i.e., $x_H^{(ND)} = 0$).

Before concluding this section, it should be pointed out that although our analysis focuses on the oil market, the main results apply to all uses of soybeans—the effects of the introduction of high-oleic soybeans for product markets in which they are an input will be determined by the price of the relevant new product that utilizes the high-oleic soybeans and the consumer valuation of the new product attribute (i.e., high oleic acid). Of course, different product markets may differ in the value consumers place on the new product attribute. For instance, although high-oleic soy oil might be a drastic innovation in the oil market, animal feed derived from high-oleic soybeans might turn out to be a nondrastic or even an ineffective innovation in the market for feedstuffs.

Implications for Domestic Producer Welfare

After having identified the factors that will determine the market effects of introducing the high-oleic soybeans into the food system, this section examines the implications of the introduction of the new soybeans for the welfare of US producers. Because, by definition, ineffective innovations (Scenario I) have no effect on the market (and thus have no effect on the welfare of agricultural producers), the analysis focuses on cases

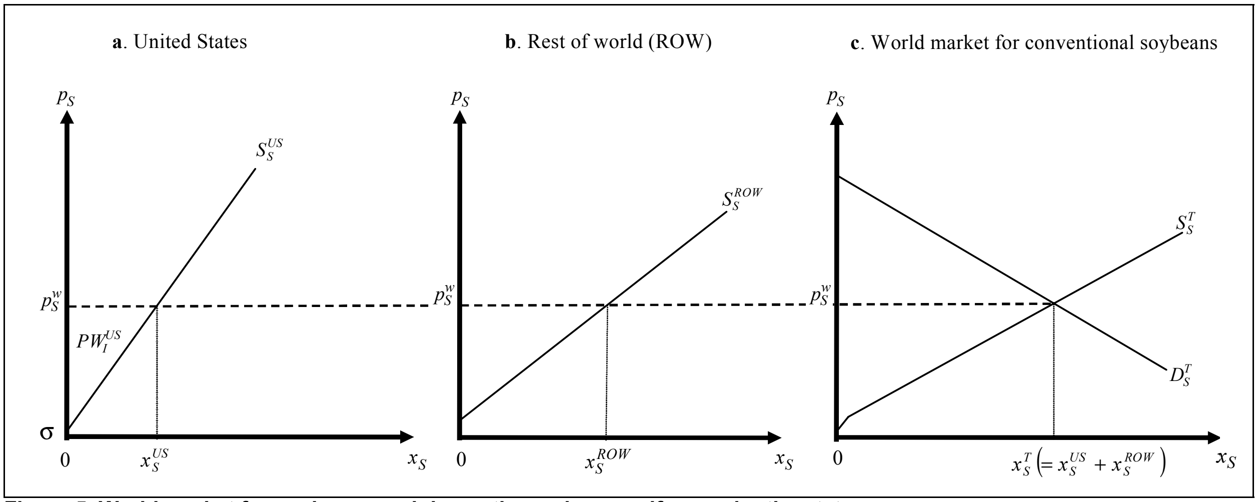

Figure 5. World market for soybeans and domestic producer welfare under the status quo.

where the high-oleic soybeans result in drastic or non-drastic product innovations.

A key assumption of the welfare analysis that follows is that the new technology is made available exclusively to US producers at no cost to them—any patenting or licensing costs involved are incurred by the US government, which then makes the new technology freely available to domestic producers that desire to grow high-oleic soybeans. We also assume that the production of the high-oleic soybeans confers no agronomic benefits (or costs) to producers—the costs of producing high-oleic soybeans are equivalent to the costs of producing their conventional counterparts.[7]

To begin, consider a stylized depiction of the world market for soybeans prior to the introduction of the new crop (i.e., under the status quo). Panel (a) in Figure 5 shows the US supply of soybeans (S_S^{US}), and panel (b) illustrates the supply of soybeans by the rest of the world (ROW; S_S^{ROW}).[8] Panel (c) graphs the total supply ($S_S^T = S_S^{US} + S_S^{ROW}$) and the total demand ($D_S^T$) for soybeans in the world market.

Note that the total demand for soybeans is a *derived demand* determined by (a) the consumer demands for products utilizing soybeans as an input in their production process (such as the demand for soy oil shown as x_S in Figure 1), (b) the supply of other inputs used in the various production processes, (c) the structure of (and the market power present in) the various stages of the different supply channels, and (d) the marketing and trading costs incurred by the trading sector and so forth. In this context, the greater the consumer demand for soy oil, for instance, the greater the demand for soybeans used in the production of soy oil and the greater the total demand for soybeans.

Assuming for simplicity and without loss of generality a perfectly competitive trading sector,[9] the intersection of S_S^T and D_S^T determines the world price of soybeans (p_S^w), which determines, in turn, the quantities supplied by the United States and the rest of the world (shown as x_S^{US} and x_S^{ROW} in panels (a) and (b) of Figure 5, respectively). Aggregate producer surplus in the United States is then given by the area PW_I^{US} in panel (a), where

$$PW_I^{US} = \frac{1}{2}(p_S^w - \sigma)x_S^{US}, \tag{17}$$

with σ being the intercept of S_S^{US}. Note that Figure 5 corresponds both to the status quo and to the case of ineffective product innovations (Scenario I).

To illustrate the potential producer welfare effects of the new technology, consider first the extreme case in which the high-oleic soybeans are introduced, and the

7. *Obviously, if the cost of producing the high-oleic soybeans were greater (or less) than the cost of producing the conventional ones, the gains in producer welfare from the introduction of the new crop would be less (or greater) than those derived in this section.*

8. *During 2003/04 the United States accounted for 33% of the world soybean production, followed by Brazil (31%), Argentina (18%), and China (8%; USDA, 2004).*

9. *If the trading sector were able to exercise market power when selling the procured soybeans downstream, for instance, D_S^T would be drawn to reflect the effective "marginal revenue" curve faced by the trading firm(s), and the analysis of the implications of the introduction of the new soybean for domestic producer welfare would remain unaffected.*

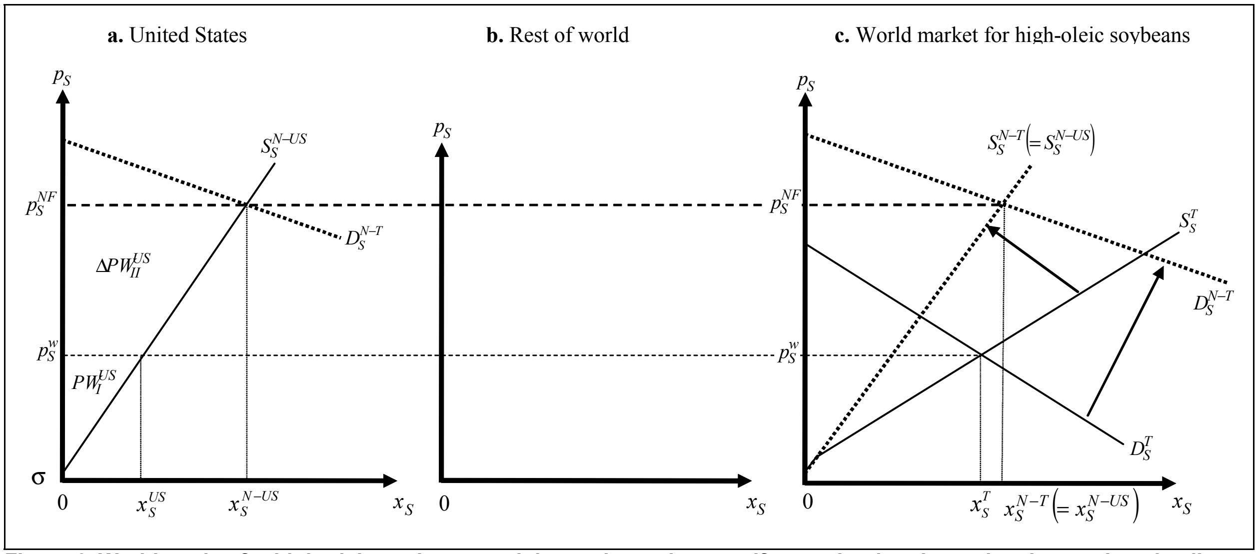

Figure 6. World market for high-oleic soybeans and domestic producer welfare under drastic product innovations in all soybean uses.

prices and preference parameters are such that the resulting product innovations are drastic in all relevant product markets (i.e., the condition specified in Equation 7 is met in all product markets where soybeans are used as an input). In such a case, conventional soybeans are driven out of the market (there is no demand for products utilizing conventional soybeans) and the United States becomes the sole supplier of (the new) soybeans in the world market. Figure 6 illustrates this case. Note that the exclusivity of the United States in the supply of high-oleic soybeans causes a reduction in the world supply of the crop—the total supply of soybeans under drastic product innovations in *all* relevant markets is given only by the US supply of soybeans (i.e., $S_S^{N-T} \equiv S_S^{N-US}$; see panel (c), Figure 6).

In addition to reducing the supply in the world market for soybeans, the drastic nature of the product innovations results in the demand for high-oleic soybeans being greater than the ex ante demand for conventional soybeans (i.e., the demand for soybeans prior to the introduction of the new crop). The reason is that, besides driving the conventional soybeans out of the market and capturing their entire market share, when the high-oleic soybeans result in drastic product innovations, they attract consumers from the substitute (lower and higher quality) product categories (see analysis in the previous sections). The outcome of these supply and demand shifts is a farm price of high-oleic soybeans, p_S^{NF}, that exceeds the price of their conventional counterparts prior to the introduction of the new technology (compare p_S^{NF} with p_S^w in Figure 6). This higher price enjoyed by the high-oleic soybeans causes, in turn, an unambiguous increase in aggregate domestic producer welfare shown by the area ΔPW_{II}^{US} in panel (a), Figure 6, where

$$\Delta PW_{II}^{US} = \frac{1}{2}(p_S^{NF} - p_S^w)(x_S^{N-US} + x_S^{US}), \tag{18}$$

with x_S^{US} and x_S^{N-US} denoting the total US supply before and after the introduction of high-oleic soybeans, respectively.

Note that although drastic innovations in all relevant product markets result in considerable welfare gains for US soybean producers, such a case may not be very realistic—as mentioned previously, the new characteristic of the crop (i.e., the high oleic content) may not be valued the same in all of its uses. Whether this turns out to be the case or not, it is certainly not necessary for the new technology to result in drastic innovations in all relevant markets in order to allow domestic producers to benefit from its introduction. Even if some (but not all) of the products encompassing the new technology constitute a drastic innovation in their respective markets, or even if the resulting product innovations are nondrastic, domestic producers will still benefit from the introduction of high-oleic soybeans.

Specifically, in the absence of agronomic benefits (or costs) from the new technology, a sufficient condition for producer welfare gains to be realized is that the total demand faced by the United States after the introduction of the high-oleic soybeans (the demand for high-oleic soybeans plus the demand for conventional soybeans when the product innovations are nondrastic) exceeds the ex ante demand (i.e., the demand faced by US soybean producers prior to the introduction of the new technology). In such a case, the farm price of high-oleic and conventional soybeans after the introduction of the new crop exceeds the ex ante price received by producers, and the introduction of high-oleic soybeans causes an unambiguous increase in domestic producer welfare.

It can be shown that due to the switch of consumers of substitute products to products utilizing high-oleic soybeans when those constitute effective (drastic or nondrastic) product innovations (Scenarios II and III in the previous section of the paper), the total demand faced by the United States after the introduction of high-oleic soybeans does exceed the demand for US soybeans prior to the introduction the new technology.[10] Because the introduction of high-oleic soybeans increases the total demand faced by the United States, it increases the equilibrium price received by farmers and, thus, it increases producer welfare. The increase in domestic producer welfare is given by

$$\Delta PW_{III}^{US} = \frac{(p_S^{NF} - p_S^{w})(x_S^{N-US} + x_S^{C-US} + x_S^{US})}{2}, \quad (19)$$

where x_S^{N-US} and x_S^{C-US} are the equilibrium quantities of high-oleic and conventional soybeans, respectively, supplied by the United States after the introduction of the new crop. All other variables are as previously defined. It should be pointed out that when adoption of the new crop is partial,[11] the equilibrium farm prices for high-oleic and conventional soybeans are the same (i.e., $p_S^{NF} = p_S^{w'}$).[12]

Figure 7 depicts the equilibrium conditions in the US market under partial adoption of high-oleic soybeans. For illustrative purposes, the markets for high-oleic and conventional soybeans after the introduction of the new technology are graphed together with the market for conventional soybeans prior to the introduction of their high-oleic counterparts. S_S^{N-US} and D_S^{N-US} show the supply and demand curves for high-oleic soybeans, respectively, while S_S^{C-US} and D_S^{C-US} depict the supply and demand relationships in the conventional market after the introduction of the new technology. Recall that S_S^{US} and D_S^{US} are the supply and demand curves prior to the introduction of high-oleic soybeans. As shown clearly in Figure 7, the intro-

10. *The derived demand for US soybeans prior to the introduction of high-oleic soybeans is given by the world demand for soybeans,* D_S^T*, minus the supply of soybeans by the rest of the world,* S_S^{ROW}*, i.e.,* $D_S^{US} = D_S^T - S_S^{ROW}$*. The introduction of high-oleic soybeans reduces the world demand for conventional soybeans, because some consumers switch their consumption to products utilizing high-oleic soybeans. This reduction in the world demand for conventional soybeans reduces the derived demand for conventional soybeans faced by the United States. The ex post demand for conventional soybeans is given by* $D_S^{US'} = D_S^T - S_S^{ROW} = (D_S^T - \Delta) - S_S^{ROW}$*, where* Δ *denotes the part of the world demand for conventional soybeans captured by their high-oleic counterparts. In addition to capturing* Δ*, the high-oleic soybeans attract previous consumers of substitute products. The total demand for high-oleic soybeans faced by the United States is then given by* $D_S^{N-US} = \Delta + \Sigma$*, where* Σ *denotes the part of the demand for substitute products switching to products utilizing high-oleic soybeans. The total demand for conventional and high-oleic soybeans faced by the United States ex post is given by* $D_S^{US'} + D_S^{N-US} = D_S^T - S_S^{ROW} + \Sigma$ *and exceeds the ex ante demand by* Σ*.*

11. *For adoption of high-oleic soybeans to be partial (i.e., for high-oleic soybeans to coexist with their conventional counterparts), the main products encompassing the new attribute should constitute a nondrastic innovation in their respective markets.*

12. *The reasoning behind the price equality between the high-oleic and conventional soybeans under partial adoption of the new crop is as follows. The introduction of high-oleic soybeans when this technology is effective (drastic or nondrastic) results in the creation of a new market. This new market includes previous consumers of conventional soybeans as well as previous consumers of substitute products.*
In the absence of agronomic benefits (or costs) from the new technology, soybean producers will enter this new market as long as the farm price of high-oleic soybeans exceeds the farm price of their conventional counterparts. The greater the share of producers that switch their production to high-oleic soybeans, the greater the supply and the lower the price of this new crop. At the same time, the exodus of producers from the production of conventional soybeans reduces the supply and increases the price of conventional soybeans.
In this setting, two equilibria are possible—one in which the world demand for high-oleic soybeans is such that it is optimal for all US producers to switch their production to the new crop (this case is depicted in Figure 6), and one in which adoption of high-oleic soybeans in the United States is partial. Although the farm price of high-oleic soybeans will exceed that of their conventional counterparts in the complete adoption case, the partial adoption equilibrium will be characterized by the equality of farm prices for the two crops. Expressed in a different way, a partial adoption equilibrium will exist when the relative prices are such that producers of conventional (high-oleic) soybeans have no incentive to switch their production to their high-oleic (conventional) counterparts (i.e., when $p_S^{w'} = p_S^{NF}$*).*

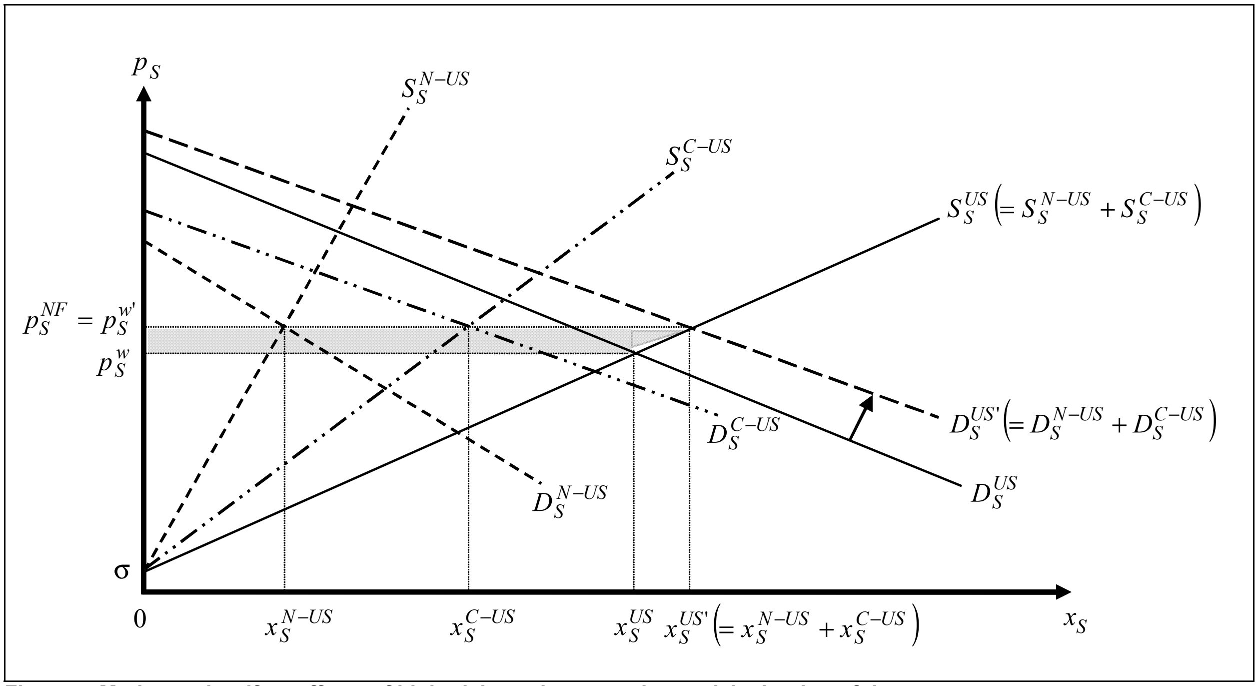

Figure 7. Market and welfare effects of high-oleic soybeans under partial adoption of the new crop.

duction of high-oleic soybeans boosts the total demand for soybeans faced by the United States, increases the price received by soybean producers, and results in the producer welfare gains shown by the shaded area.

The magnitude of this producer welfare increase is determined by the market effects of the new technology, which have been shown in the previous analysis to be determined by the pricing of products utilizing high-oleic soybeans and the consumer attitudes towards the new product attribute. In particular, the greater the consumer valuation of high oleic acid in soybeans and/or the lower the price of products encompassing the new technology, the greater the demand for these products, the demand for high-oleic soybeans (supplied exclusively by US producers), the total demand for soybeans faced by the United States, and the producer welfare gains from the introduction of the new technology.

Summary and Concluding Remarks

This paper develops a simple model of vertical product differentiation to examine the economic effects of the introduction of a consumer-oriented, second-generation genetically modified soybean developed at the University of Nebraska. In particular, the study focuses on the market and producer welfare effects of the introduction of a new soybean that contains high oleic acid and is licensed exclusively to US soybean producers. The paper identifies the factors that will determine whether the new technology is effective and, if so, whether it results in drastic or nondrastic product innovations. The implications of the new technology for domestic producer welfare are analyzed within this framework.

Analytical results show that the market and welfare effects of the introduction of high-oleic soybeans are determined by the relative prices of products utilizing the new soybeans as an input in their production process (which are determined, in turn, by the structure of the different supply channels, their production technologies, and the costs associated with the segregation and identity preservation of the new crop), the distribution of consumer preferences, and the benefits consumers perceive from the new product (i.e., the value consumers place on high oleic acid).

The lower the prices of products using the new soybean as an input and/or the greater the value consumers place on the new product attribute (i.e., high oleic acid), the more likely it is that the new technology will result in drastic product innovations, and the greater the market acceptance and consumption share of the new high-oleic soybeans will be. When the new technology is licensed exclusively to US producers, a high consumption share of high-oleic soybeans translates into increased market share of the United States in the world market for soybeans and welfare gains for domestic producers. When the value consumers place on the new product attribute is sufficiently high, the introduction of high-oleic soybeans is shown to drive the conventional soybeans out of the market, attract consumers of substitute products (such as palm, sunflower, and canola oils), and confer welfare gains to all domestic producers of soybeans.

Overall, the analysis reveals that the effectiveness and success of high-oleic soybeans will be determined by relative prices and the consumer valuation of the new product attribute. The fact that altering production technologies, segregation systems, and market structures across numerous supply channels is generally a formidable task, suggests that a successful commercialization strategy might need to focus on the consumer. Such a strategy mix would most definitely need to include the determination of the value that high oleic content adds to different products (such as soy oil) as well as an effective communication of potential health and other benefits to consumers.

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