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The Dynamics of Biotechnology in the Soybean Marketplace

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The goal of this paper is to explore market system dynamics associated with recent and potential future adoption of biotechnology in the soybean marketplace. The rapid and dramatic adoption of herbicide-tolerant varieties has had a major production impact in the United States, Argentina, and Brazil. Economic benefits from that adoption accrued to adopting and nonadopting producers as well as to firms providing the technology. Firms providing substitute weed control systems suffered economic losses. To this point, biotechnology's effects have been limited to agronomic characteristics. Future innovations may provide enhancements to the output traits of soybeans. However, for those benefits to be captured in the marketplace, substantial changes in the existing commodity market channel are likely. Market channel alternatives and the dynamics of that market system change are examined in this article.

Key words: market channels, economic advantage, biotechnology adoption, soybeans, herbicide resistance.

Introduction

Based upon market behavior since the mid-1990s, the track record of producer adoption of biotechnology-enhanced soybeans is clear and consistent. Where regulations allow, producers will plant soybean seeds that have been enhanced through biotechnology. Introduced only in 1996, herbicide-tolerant soybeans were planted on 81% of US soybean acres in 2003 (United States Department of Agriculture [USDA], 2003). That adoption level is spread fairly uniformly across the major soybean-producing states. The states with the lowest adoption levels (North Dakota and Ohio) still have three out of four acres planted to herbicide tolerant varieties (USDA, 2003). South Dakota has the highest adoption rate of 91% (USDA, 2003).

In Argentina, the adoption of herbicide-tolerant soybeans has been equally widespread. Indeed, data from the International Service for the Acquisition of Agribiotech Applications show that in 2002, herbicide-tolerant soybeans were planted on more than 36 million hectares globally, accounting for more than 60% of the total acreage planted to biotechnology-enhanced crops. Even in Brazil, it is believed that the acreage of herbicide tolerant soybeans planted in recent years exceeded 15% of the total acreage (Pew Initiative on Food and Agriculture, 2000; Animal Biotechnology, 2003). This occurred even though, at that time, regulations officially prohibited the planting of seeds using this technology.

The goal of this paper is to explore market system dynamics associated with recent and potential future of adoption of biotechnology in the soybean marketplace. The paper's next section discusses the economic effects in the soybean marketplace based upon experience to date. The analysis first will consider conceptually how the effects of such an innovation should impact upon the market, and then data on actual effects will be evaluated. The remainder of the paper explores likely market structure effects associated with the potential for second-generation, or output-enhancing, traits. The dynamics of change in commodity markets are investigated through the application of system dynamics. Then, a range of market channel options, from commodity to vertical integration, is assessed relative to differing uses for soybeans with output-enhanced traits.

Winners and Losers in the Market

The market for a global commodity such as soybeans is, in the best of times, noisy, turbulent, and confusing. Global economic forces—interest and exchange rates, for example—affect the demand for food and for soybeans as well. Events and political actions in major producing and consuming nations interact to confound or accelerate those global forces. Weather throughout the world adds to the uncertainty. Despite this turbulence, soybeans are traded in thousands of local markets each day and the world price for soybeans in the near and intermediate future is visible at key exchanges, such as the Chicago Board of Trade. Unraveling the effect of one technology—even one as significant as herbicide-tolerant soybeans—can be difficult. Therefore, the following discussion will first discuss key concepts, which will help to frame the likely effects of technology in the soybean market. Then this frame will be employed to interpret actual data from recent years.

Concepts Regarding the Effects of Technology Adoption

Adoption of a major new technology is seldom instantaneous, nor does the adoption rate tend to occur uniformly over time. Both the characteristics of the potential adopters and of the technology itself interact to affect the rate and pattern of adoption. Generally, the potential technology will be employed within a larger system. In the case of herbicide-tolerant soybeans, the immediate economic system of interest is the farmer's crop production system. Because the technology was being delivered through seed and employed herbicides already in use, there were relatively minimal systematic changes required by the farmer to adopt herbicide-resistant soybeans. The second economic system of interest is the marketing system. To this point, the marketing system changes required of adopters have been minimal. Actions that impose labeling requirements for international trade could increase marketing system complexity and affect future adoption levels. For so-called second-generation, or output-enhancing, traits, market system changes are likely to be required. For these potential innovations, adoption patterns and rates will be affected by differing dynamics than those that have been experienced since 1996. Those dynamics are discussed later in this paper.

Of course, adoption of any technology requires that the decision maker perceive some benefit from doing so. In the case of herbicide-resistant soybeans, an economic benefit through a reduction in the total cost of weed control was expected. Even though the biotechnology-enhanced seed may cost more per unit than does nonenhanced seed, reductions in the costs of herbicides could offset that cost. Therefore, it is the total cost of weed control that must be considered.

The marketplace for soybeans is dynamic. As a technology is introduced, the economic effectiveness of that technology is affected by a host factors such as demand, capital costs, and government policies. In addition, the role and responses of competing technologies must be explicitly understood if we are to understand the pattern of adoption of a specific technology. Decision makers in firms that provide the competing technologies are faced with a challenge when an effective alternative technology enters the market. They face the prospect of reduced profitability if they lose market share or if their profit margins are reduced. The first response of such decision makers is to observe early market share and performance results. After all, the new technology may not perform well in the actual production environment.

If, however, the new technology does perform well, these decision makers must assess their response options quickly and carefully. In particular, they need to consider how their pricing tactics should respond, if at all, to the presence of the new technology in the market. One response is to strive to maintain current price levels, even though market share is likely to decline. An alternative response is to lower price levels substantially in an attempt to compete for market share. Many factors would affect any firm's actual response. In general, however, an economic factor of considerable importance is the ratio of fixed costs to variable costs associated with the production of their products. As long as the reduced price will generate sufficient cash to exceed the variable costs, selling a unit of product at the reduced price will contribute cash to the firm and will at least partially offset the fixed costs. Therefore, in industries and sectors where the ratio of fixed to variable costs is high, significant price reductions can occur in response to effective new technologies (Shapiro & Varian, 1999). In the short run, the agricultural chemical market can be characterized as having relatively high ratios of fixed to variable costs. Therefore, introduction of an effective, cost-reducing weed control technology could be expected to lead to price reductions of competitive weed control products.

Enhanced farmer profitability was noted as an important motivator for adoption of herbicide-tolerant soybeans. Early in the adoption process, we would expect there to be potential and actual economic benefits to those farmers who adopt those varieties relative to farmers who do not adopt. As the extent of adoption expands, a somewhat counterintuitive result is likely to occur—if the providers of competitive weed control systems respond as described in the preceding paragraph. Over time, the net per-acre returns for adopters and nonadopters should come into relative balance. For many agricultural technologies, we expect that the benefits to early adopters would decline over time as expanded production leads to lower output prices and the benefits of the technology are accrued by consumers. That is not the phenomena being discussed here. Rather, the dynamics associated with the market structure of the agricultural chemical industry lead to declining price levels for alternative weed control approaches. Under these circumstances, both adopting and nonadopting producers benefit from reduced weed control costs. For early adopters, the absolute advantage that attracted them to the technology may not erode. However, the advantage relative to nonadopters should decline. Conceptually, at least, if an effective technology of this type is introduced, farmers (who use the new technology or competitor technologies) and the company providing the new technology should gain economically. Firms providing the competitor technology should be economically disadvantaged. The actual extent of any gains and losses, of course, is unique for each specific circumstance.

Evidence from the Marketplace

As noted in this paper's introduction, one measure of the effectiveness of herbicide-tolerant soybeans sends a clear and consistent message. The massive growth in the use of seeds with that technology indicates that producers believe that they are obtaining benefits from use of the technology. Attempts to document definitively the extent of any economic gain, however, have not resulted in such a clear message. Data from experimental trials, although certainly useful, suffer because the complications that occur in large-scale commercial production settings are excluded from the trials. Data from individual farm operations tend to be confounded by the effects of factors other than the weed control system and because the accuracy of farmer accounting systems can be quite variable. Moreover, because of weather variability, it is desirable to have results from more than one production season.

Norvell (2002) provides an especially insightful analysis based upon data from actual farm operations for the period 1997–2000. The data used in this analysis were derived from records of the Endowment farms of the University of Illinois. These farms are located in northern and central Illinois. Although the university provides professional farm managers for the land, the individual farming operations are run by commercial farmers leasing the land from the university. Because of the use of crop share leases, key production, cost, and return information is reported to the university in a uniform manner.

As shown in Table 1, the use of herbicide-tolerant soybean seed on these farms also followed the pattern of rapid increase over the 1997–2000 period. In 1997, less than one in four of the approximately 5,000 soybean acres in the sample were planted to herbicide-tolerant seed. By 2000, the ratio had increased to nearly one in two acres. Although the interest here is on the effects of biotechnology-enhanced seed, a dominant feature exhibited by the data is the importance of market price to farmer wellbeing. The relatively high 1997 revenues resulted from higher prices in that year. For the remaining three years (1998–2000), output prices fell due to worldwide demand and supply conditions, drastically reducing the net returns earned—whether herbicide-tolerant or non-herbicide-tolerant seeds were planted.

Table 1. Performance comparison between herbicide-tolerant and non-herbicide-tolerant soybean seeds on the University of Illinois Endowment farms, 1997–2000.

Year	1997	1998	1999	2000	Period average
Number of farms[a]	37	38	37	35	37
Total tillable acres	4,909	5,056	5,148	5,150	5,066
Percent planted to herbicide-resistant seed	24.3	49.1	52.0	46.6	43
Gross revenue per acre using herbicide resistant seed	361	302	241	232	284
Gross revenue per acre using non-herbicide-resistant seed	372	283	250	250	289
Seed and chemical costs per acre using herbicide-resistant seed	42	45	40	42	42
Seed and chemical costs per acre using non-herbicide-resistant seed	52	46	44	42	46
Net returns[b] per acre using herbicide-resistant seed	319	257	201	190	242
Net returns[b] per acre using non-herbicide-resistant seed	320	237	206	208	243

[a] *The farms included in the sample were not limited to land within the Endowment farms; instead the producers generally considerable acreage in addition to that included in this data set.*

[b] *Returns net of appropriate seed and chemical costs only.*

In 1997, the seed and chemical costs for those acres planted to herbicide-tolerant seed were sharply lower ($10 per acre) than were the corresponding costs for acres planted to non-herbicide-tolerant seeds. By 2000, however, those costs were equal. This occurred as the costs for the non-herbicide-tolerant approach declined over the four years. That result is consistent with the conceptual notion that firms providing alternative technologies would lower their price in an attempt to slow or halt the decline in market share. Net returns per acre were nearly equal over the 1997–2000 period for the acreage in this sample.

Gianessi and Carpenter (2000) explore the effects of transgenic soybeans using data from USDA surveys of the 15 major soybean states. Their analysis highlights dramatic price declines between 1995 and 1998 for alternative herbicide control approaches. For example, the price per unit of active ingredient of chlorimuron and imazethapyr declined by more than 40% in 1997 and 1998.

Given that alternative weed control systems rapidly and dramatically declined in cost, it is intriguing that the adoption of herbicide-tolerant soybeans seeds continued to increase after 2000. The increase in actual adoption would suggest that the finding of nearly equal per-acre returns does not fully capture the benefits that are perceived by farmers. These benefits might have to do with reduced time requirements or a greater "window" during which the herbicide control can be applied, thereby reducing the farmer's risk of inadequate control.

The Dynamics of Change in Marketing Systems

If widely accepted by consumers, agricultural biotechnology offers the potential to provide substantial benefits, but also challenges, to participants throughout the commodity production and marketing system. The existing commodity system is not designed to produce and deliver diverse sets of differentiated output. The following discussion will examine the dynamic interactions likely to result in a setting where biotechnology drives structural change in the production and marketing system.

Investing in a Vision

The vision that there are potential benefits from biotech commodities has driven investment into research and development initiatives. Figure 1 suggests that *Theoretical Value from Biotech* supports (*S*) the *Speculative Investment* that in turn supports *Biotech Development*. This tends to be a reinforcing process (*R*), where new developments generate more ideas for value that drive more investment. For many types of biotech value traits, this depicts where we are in the current situation—especially for value traits that provide benefits to participants further down the value chain beyond the producer. The bold lines that intersect the linkage between speculative investment and biotech development denote that there are time delays between the decision to invest and actual development of innovations.

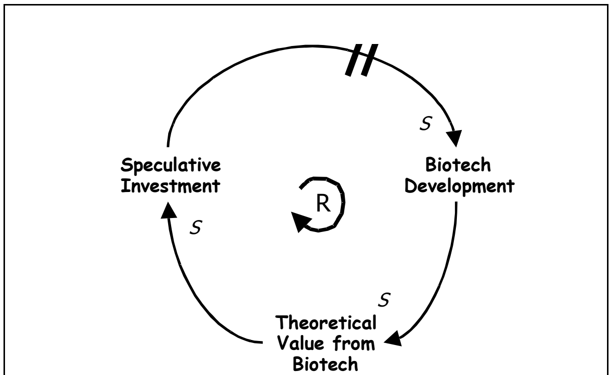

Figure 1. The potential for value drives development.

Moving from Theoretical Value to Realized Value

As development continues and biotech-driven quality improvements become a reality, it becomes possible to move from theoretical value to realized value. Figure 2 expands our diagram to illustrate that *Transportation and Handling Infrastructure* will be needed in conjunction with biotech development to generate *Realized Value from Biotech*. Other system components will be needed to facilitate the full adoption of biotech grains. For example, the factors below are just as important as the transportation component:

- new marketing and business arrangements that will be needed to facilitate the redistribution of value through the value chain;
- the utilization of information technologies;
- the evolution of testing technologies; and
- public acceptance of different kinds of products.

Figure 2 illustrates where the current structure is lacking today and most likely in the near future unless changes are made to the transportation and handling infrastructure. That is, the amount of biotech development is continuing to advance and build theoretical value from biotech, while (without investment) the transportation and handling infrastructure can quickly become a limiting factor in realizing the potential value.

The Incentive to Invest in Infrastructure

Investment in transportation and handling infrastructure is fundamentally different from the investment in biotech development. Investments in biotech are large and speculative, but perceptions of high long-term payoffs justify investing. This tends to attract long-term investors. On the other hand, investment in transportation and handling infrastructure is more mundane but has a more tangible outcome. There is little question that a particular infrastructure can be built. The speculation is

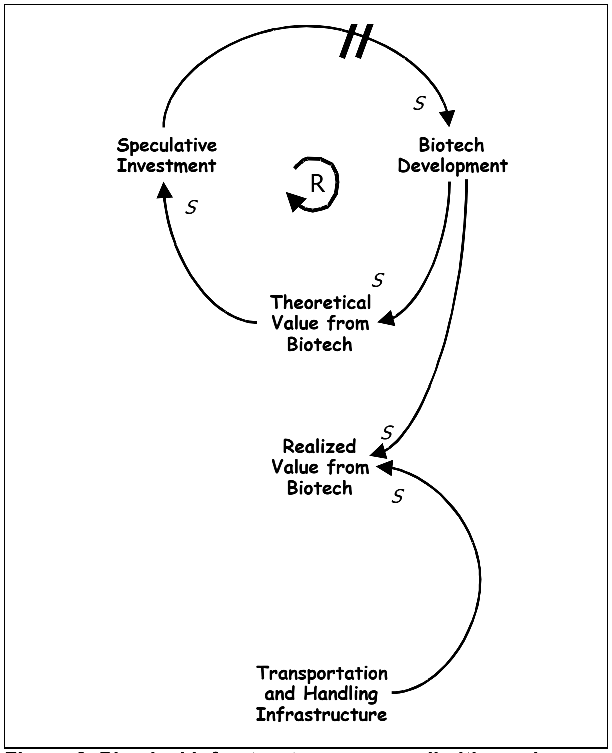

Figure 2. Physical infrastructure as a gap limiting value realization.

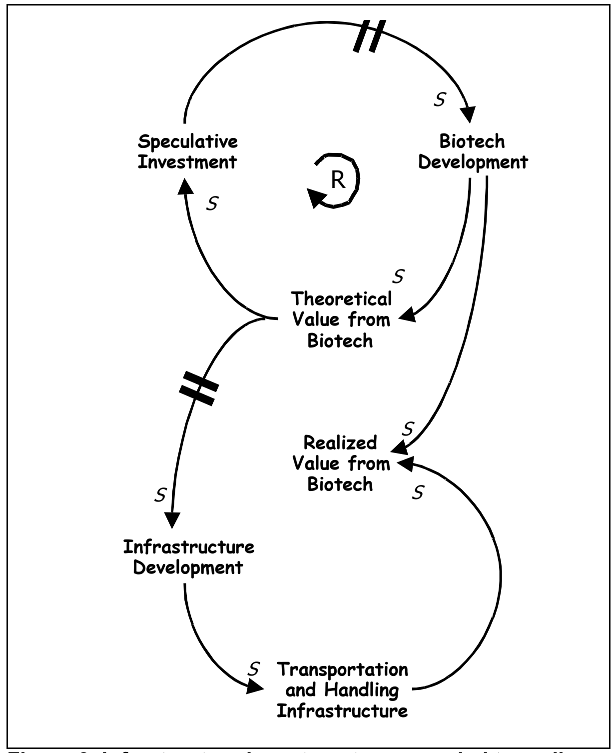

Figure 3. Infrastructure investments are needed to realize market value.

whether the market will provide adequate return to the transportation and handling infrastructure to provide sufficient return to the investment—especially in a sector that has historically been characterized as highly competitive with very narrow margins. However, both components are important if value is to be actually realized from biotechnology-enhanced soybeans.

Figure 3 builds on the previous figures to include a very important linkage from the theoretical value from biotech to *Infrastructure Development* that supports the development of the transportation and handling infrastructure. The notion here is that it as the theoretical value from biotech increases over time, it will reach a threshold, at which time someone in the system will become convinced that it makes sense to invest in the development of infrastructure. (Of course, the perceived theoretical value can decline, which would retard investment.) The two short, bold lines that intersect the linkage between theoretical value from biotech and infrastructure development suggest that this time delay is likely to be both significant and lengthy. Over time, this will provide the infrastructure needed to realize the value from the biotech developments. The time lag between the point where the biotech product is ready for market and the time when it is actually generates market returns is critical. There is the potential for substantial lost opportunity if a biotech product is ready for market, but sits stagnant (even for a couple of years) while the necessary infrastructure is developed.

Closing the Loops

It will be important to understand the dynamics of the continued evolution of the transportation and handling infrastructure as the system matures. Figure 4 identifies feedback loops that will provide a return to those who invested in biotech development and infrastructure development. Over time, these feedback loops will generate varying degrees of additional investment, depending on how successful (profitable) the existing products have been. Again, the magnitude of any delays between the time when value begins to be actually realized (realized value from biotech) and infrastructure development will significantly affect the pace by which returns accumulate and fuel further investment.

The time lags noted in the preceding diagrams are of critical importance. They identify a significant mismatch between the processes by which expectations are formed that lead to investment in biotechnology development versus investment in infrastructure. Although infrastructure is not needed until crops from biotechnol-

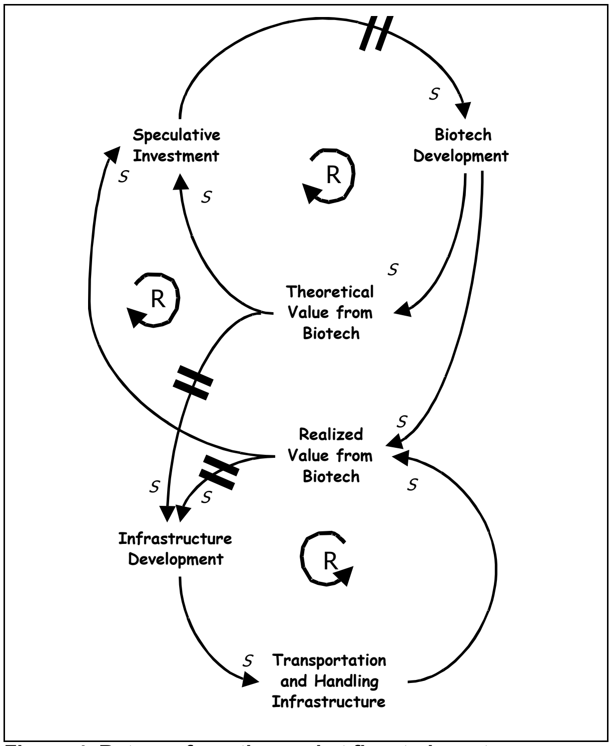

Figure 4. Returns from the market flow to investors.

ogy are in the marketplace, delay in the availability of that infrastructure will reduce profitability and restrain further investment in biotech development.

Biotechnology and the Commodity Marketing System

The production and marketing system for soybeans and the other major commodity crops in the United States is designed to provide maximum value through the low-cost delivery of massive amounts of homogenous grains and oilseeds.[1] Key characteristics, which result in successful operations in the current commodity setting, conflict with the needs that appear to be required for effective marketing of bioengineered crops.

Expected Challenges to the Commodity Marketing System

Even though the biotechnology revolution is still in its infancy, significant transportation, handling, and logistical implications can be identified that may result from the continued adoption of bioengineered soybeans. For two very different reasons, it now appears that crop identity will have to be maintained in production and marketing supply chains for at least some portion of the crop.

So-called first-generation crops were altered to enhance agronomic performance. Because output traits were not affected, segregation of these crops was not expected to be necessary. In some international markets, however, acceptance of bioengineered crops is a controversial issue. Labeling of bioengineered crops currently has been mandated for some uses. Therefore, separate handling systems for herbicide-tolerant soybeans may need to be created because of these labeling requirements.

The most significant impact of biotech crops on crop transportation, handling, and logistical systems should occur with the second generation of biotechnology, when crops with quality-related traits that have added value for specific end users become available. The added value of these crops is found beyond the farm level. Potential examples include high-lysine corn, high-oleic soybeans, or wheat with improved processing traits. These products will require segmentation to preserve their identity through the grain-handling systems to the point where the value is captured. If grain with specific end-use value is commingled with other grain, value is likely to be lost.

Alternative Marketing Channels Defined

The following discussion will delineate possible market structures that may develop to accommodate the production and marketing of soybeans with enhanced output traits. As a starting point, the marketing channels described as part of the US Grains Council's 1998-1999 Value-Enhanced Corn Quality Report are employed (Cunningham, 2000; Sonka, Schroeder, & Cunningham, 2000). The US Grains Council marketing channel definitions work well for describing most systems used for the production and merchandising of value-enhanced soybeans. However, a few modifications to these structures may be useful as we look at the impact of biotech enhanced output traits on the soybean marketing system. Table 2 identifies the channel alternatives, their differentiating characteristics, and the modifications made for

1. *In reality, of course, homogenous commodities dominate the current system; however, there are a variety of value-enhanced crop products on the market as well. In general, market transactions and transportation logistics work smoothly for these niche products in small volumes and with premium pricing.*

Table 2. Alternative marketing channels for grains and oilseeds.

Differentiating characteristics	Level 0 vertical integration	Level I identity preserved	Level II specialty	Level III super commodity	Level IV standard grade
Relative value/ premium	Any (high to low)	High	Medium	Low	None
Buyer control	Complete Multi-year	Variety Production Practices Certification Other	Min/Max Attributes	Attribute preferences	Grades only
Attribute testing	Integrator's discretion	Buyer's discretion	Cost/value-driven	Efficient/consistent	Grade-driven
Types of producer contracts	NA	Acreage Production Bushels	Production Bushels Normal/open	Normal/open	Normal/open
Producer linkages	Complete	High	Moderate	None	None
Minimum segregation	Any desired	Farm	First point of sale	Merchandiser determined	Merchandiser determined
Product volumes	Any desired	Low	Moderate	High	Very high
Information carriers/ traceability	High	High	Moderate	Low	None

this study. Vertical integration was added as an alternative marketing channel, and traceability was added as another differentiating characteristic. The new additions are shaded in the table.

Vertical integration, as an alternative marketing channel, recognizes that some end users may require total control over production and handling of inputs. The original channels assume a basically traditional ownership structure with independent control of production, handling, and processing functions. The original channels do account for the use of production contracts to secure production but not for the complete integration of the system.

Vertical integration provides buyers with an even higher level of control than the identity preserved (IP) channel. A significant advantage of vertical integration is that the system could be immediately responsive to the integrator's needs.[2] The integrator would not have to spend time and resources encouraging producers to raise the types of traits they needed. The integrator's entire production could be directed to any trait that they wanted each year.

Vertical integration would most likely be used for high-value products where the integrator wanted complete control over the production and handling practices to preserve the product's quality and identity. Vertical integration may be used as a system to keep the integrator's production out of the commodity channels in cases where the specialty product may have undesirable effects if used in the wrong application. For example, in the production of soybeans with pharmaceutical traits, it may be very important to keep the enhanced soybeans out of the commodity channel. Usually, the segregation challenge with specialty crops is to keep other types out of the specialty channel—here the problem is the reverse. Vertical integration could give the integrator greater control over the production and handling of soybeans to limit the potential for the specialized soybeans to "leak out" into the commodity stream.

The ability for soybeans to "carry" information and be "traceable" to its origin was added as another differentiating characteristic of marketing channels. The increased number of end-use traits, food safety concerns, and consumer demand for information about the food they buy are all driving the need for better traceability. In the future, it will become increasingly important to be able to trace the input source of an end-use product back through processing, handling, and production.

When looking across the marketing channels, it is clear that the ability for soybeans to carry information about its past varies over the channels. In the vertical integration channel, the potential for information transfer and traceability is high. Integrators could maintain information about given lots through their system. Identity preservation systems are set up to maintain informa-

2. *As a form of business organization, vertical integration has disadvantages, including the challenge of managing business processes at differing levels of the supply chain. Most of these are not unique to the issue of biotechnology and will not be addressed here.*

tion about the identity of the soybeans. This is in sharp contrast to the standard grades or the commodity channel, where there is usually no descriptive information transferred with the soybeans.

Currently, the ability to track information about grain history along with the product flow is constrained primarily by the level of segregation performed. Segregation that is maintained all the way from the farm level can enable detailed information to be carried with the grain about its history. An example would be an IP system designed to deliver organically grown soybeans. Here the producer, production practices, and variety can be determined.

Advances in biotech may assist in product traceability. Gene markers might enable grain with specific traits to be marked with a visible indicator or even labeled by the producer. These advances may be a few years away but would dramatically change the system's ability to trace soybeans back to their origin. Traceability would no longer have to be linked to segregation. Mixed lots could still be traced back to their origin.

Summary

This paper explored market system dynamics associated with recent and potential future adoption of biotechnology in the soybean marketplace. The rapid and dramatic adoption of herbicide-resistant varieties has had a major production impact in the United States, Argentina, and Brazil. Economic benefits from that adoption accrued to adopting and nonadopting producers as well as to firms providing the technology. Firms providing substitute weed control systems suffered economic losses.

To effectively produce and deliver soybeans with differentiated traits to customers, alternative market channel mechanisms and infrastructure will be needed to extend the capabilities of today's commodity system. A typology of alternative market channels is specified in this report. These alternatives bracket the plausible range of expected needs. The alternative channels are categorized in terms of eight distinguishing characteristics deemed important to industry participants. Each of the alternatives is plausible today, although expected advances in measurement technology and scale efficiencies will reduce future costs. Therefore, mechanisms do exist (or could be expected to rapidly emerge) by which a whole range of differentiated output could be marketed. Further, because of differing requirements and value opportunities, bioengineered soybeans could be marketed in each of the alternative channels. Moreover, some output types may be marketed in more than one channel.

Investigation of the dynamics of marketing systems facing technological change identified a fundamental mismatch in the decision expectations between investing in biotechnology and investing in transportation, handling, and logistical infrastructure. Yet if soybeans with differentiated output traits through biotechnology are to be effectively provided in the marketplace, investment in transportation, handling, and logistical infrastructure also is essential. This investment will be required to facilitate development of alternative market channels. In addition, it is likely that relationships along the agricultural supply chain will need to change substantially. The most visible of these changes would be horizontal and vertical consolidation, as well as alliances, among agricultural firms replacing the traditional commodity channel.

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