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ECONOMIC CHANGES FROM THE USE OF
BIOTECHNOLOGY IN PRODUCTION AGRICULTURE

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I. Introduction

Although the underlying science for biotechnology may be different than the science for previous technological changes in agriculture, the economic impacts of biotechnology products may be similar to the many diverse technological changes that have occurred previously. However, it is not possible to generalize and conclude that all biotechnology will have a similar impact as hybrid corn, vaccines, or even the cotton picker. In actuality the impact of biotechnology products will depend upon the characteristic of the product and how it impacts the production function (process) as well as the market structure for agricultural inputs and outputs.

In this paper I discuss the potential economic impact of biotechnology in production agriculture. I begin by presenting the challenges and difficulties in performing economic research when very little, if any, economic or production information is available on biotechnologies. I then discuss the concepts of cost-reducing versus output-enhancing technological change and argue that little impact differences exist. Next I argue that rapid technological change results in low average returns in agriculture, but continuous early innovators earn higher returns. I then present some of the economic results that we have obtained on some plant and animal biotechnologies and finish with some conclusions.

II. Completing Economic Research on Biotechnology

Economic research on agricultural biotechnology centers on technology forecasting and measuring the economic impact of technological change. Technology forecasting typically entails estimating when a product will be developed, commercialized, or adopted. Techniques include the familiar Delphi survey and estimating adoption curves, although other techniques such as cross impact analysis, morphological research, and catastrophe theory do exist (Makridakis, et al.). Many of these are either ad hoc in nature or require the information input of experts in the specific technologies. Since a large number of ex post technological impact analyses have been performed (Norton and Davis), a useful area to pursue may be historical analogies (Ayres). Some technology forecasting techniques also attempt to measure the economic impact in a rudimentary manner.

Economists typically estimate economic impacts by econometrically estimating demand and supply functions, or associated functions, and then shifting those curves to determine the economic impact (Osteen and Kuchler). Another technique entails mathematically programming the production and

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marketing process, which requires defining the objective functions of the decisionmakers. Hybrid combinations of the two basic approaches can also be used. A limitation of econometrically estimated functions is that they pertain to historical prices and technologies and thus are not relevant under new technology. Most technological change will shift the supply curve of a commodity. The difficulty is determining the character of the shift. Not only is it difficult to ascertain the magnitude of the shift, there is often no reason to expect the shift to be parallel as we have shown with bovine Growth Hormone (Magrath and Tauer, 1986b). The size and type of shift will affect any estimates of consumer and producer surplus (Lindner and Jarrett). In addition, the interesting questions to be answered include more than price, quantity, revenue, and utility. With the potential technological change magnitudes that are being discussed, the impact on the structure of agriculture and resource usage would be tremendous. This necessitates extending the research methods to answer those questions. It appears those requirements have stymied research on the economics of biotechnology in agriculture since it requires building a total system of the economic relationships involved. Whether that is accomplished by mathematical programming or econometric estimation or some combination, it is still necessary to speculate what the technological change will do to the production function. This requires close working relationships with knowledgeable biological scientists in order to develop feasible responses to inputs that would be expected.

An example of this type of effort is with the bovine Growth Hormone. Early research results administering the compound over a short response period found an increase in milk production with no increase in feed consumption (Peel, et al.). Those results were published as observed. Some took those results and modeled accordingly. Others were more skeptical and talked with scientists to determine if this could indeed be expected to occur over a longer term administering of the compound. It was not expected, and further research results brought that out.

It is sometimes debated whether economic research should be performed when incomplete information is available on the technology involved. The answer depends upon whether the results of the research provide information that is useful and not misleading. Nonetheless, in reporting the results it is critical to acknowledge that the results are only tentative until additional information becomes available.

III. Cost-Reducing versus Output-Increasing Technology

The various impacts of technological change on the production function were discussed decades ago by Earl Heady. Much of the continuous debate still hinges on semantics of whether a new input has been created or an improvement has been made in an old input. It is also possible to delineate in terms of a shift in the production function or a new production function. And, especially now with biotechnology, we may have entirely new products. Partly as a result of the difficulties in defining technological change with the production function, many economists prefer to discuss technological change in the context of a cost curve, where farmers have selected the least cost combination of inputs, however defined, to produce a given amount of product.

Technological change permits a farmer to produce a given amount of a product at a lower cost or the technology would simply not be adopted. This can be illustrated as a lowering of the cost curve. The amount produced may be more or less than the amount produced before adoption, depending upon the character of the technology and how it reduces the cost curve. Producers will only maintain their previous level of output if the technology shifts their total cost curve parallel so that marginal cost is not altered, an event that is possible but not plausible.[1] Regardless of whether a farmer increases, decreases, or maintains his current level of production, his profit must be increased (or losses reduced) with the new technology or he would simply not adopt it. That additional profit does not go unnoticed by other farmers.

If technological change reduces the cost of producing a given amount of output, then additional farmers will be attracted to producing that product under the new technology. The market result is an increase in production and a reduced output price. Since the demand for agricultural products is generally inelastic, total revenue to the sector falls.

A concept that has recently become popular is that cost-reducing technological change is beneficial to the agricultural sector while output-increasing technological change clearly is not. Universities have crop seminars touting cost-reducing technologies. The distinction is even contained in experiment station and USDA reports. The erroneous distinction is easily made because clearly cost reduction will benefit all farmers if they do not increase their production. In contrast, output-increasing technology by definition increases output and then lowers prices. The fault in the logic is the premise that farmers will not increase their output if their cost of production is reduced. However, not only will farmers currently producing the commodity generally shift more of their resources to the commodity if the marginal cost of production is decreased, other farmers not currently producing the commodity will shift to that commodity since average cost would be reduced. This is especially the case when profit margins in most commodities are slim or nonexistent.

John Reilly has recently shown that the supply curve is increased more with a one percent increase in output (output-enhancing) than with a one percent decrease in input cost (cost-reducing). The empirical evidence leads him to state that the additional impact of output enhancing technological change is minor in comparison to the output increase of cost-reducing technological change. In either case, given the demand and supply characteristics in agriculture, producer welfare (surplus) would be reduced, leading to lower returns to fixed factors like land and labor.

The reason the cost-reducing statement is made by the land grant institutions, the USDA, and farm organizations is political. During times of a farm crisis it would be difficult to obtain research funds for science and technology that could put more farmers out of business. And, the support for public agriculture research comes from farmers and their organizations, and not generally from the consumers who benefit because food is being produced with fewer resources (including fewer farmers), and thus at a lower cost.

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[1]It may be possible that marginal revenue (price) and marginal cost both change such that the optimum output of a farm does not change.

IV. The Dynamics of Continuous Technological Change

Earl Heady argued many years ago that agriculture is a low-return industry since continuous technological change results in chronic excess resources in the industry. Because there is a need for fewer resources, resources used by the industry earn a lower return until they leave agriculture. That exodus is not immediate nor necessarily efficient, especially with labor.

Although continuous technological change in agriculture may result in low returns, it is important to realize that those low returns are only average returns. Of importance also is the distribution of those returns over different types of farmers. An agriculture with low rates of technological change will have a higher average rate of return than an agriculture with high rates of technological change. However, the distributions of those returns will be much greater with higher rates of technological change. An early adopter can benefit from increased output from technological change before others adopt and prices fall with increased output. If a continuous stream of technological changes exists, then continuous early adoption provides a farmer with a higher rate of return than he could earn if no technological change occurs.

This phenomenon was recognized by Welch who found that the rate of return to education was higher in U.S. agriculture than agriculture in India. The data were from a period when technological change in the U.S. was much greater than in India, which at the time was stagnant. He claimed that the value of education is high in agricultural production in developed countries since it aids in early adoption. An interesting result is that education may keep an individual in agriculture because the opportunity cost to leave agriculture is high. In contrast, it is often thought that education provides the opportunity for a farmer to find employment outside of agriculture.

Thus, we may expect to see the potential early adopter of biotechnology actively supporting research that would increase output or reduce cost, although the result on the agricultural sector would be to shift the supply curve to the right. Since demand for agricultural products is inelastic, lower total revenue to the sector would result. The early adopter might even have some desired optimal rate of technological change given the benefits and costs of adoption.

It is also rational for laggard adaptors to resist technological change that increases supply. They may be fighting for their survival. In fact, it is entirely rational for a state government or agency to resist technological change if that agricultural industry is important to its state's economy. Since demand for agricultural products is inelastic, an increase in output would decrease revenue. With a multiplier effect, the end result can be much lower state income. However, since Iowa farmers have generally shown themselves to be early innovators, the state's income may be enhanced rather than reduced with continuous technological change.

These concepts of continuous technological change have been labeled by Cochrane as the "agricultural treadmill." Since technological change increases output and lowers prices, a farmer must adopt in order to survive. Since continuous technological changes occur a farmer must stay on the adoption treadmill or fail to remain competitive. Not every farmer, however, is able to remain on the treadmill.

The dynamics of technological change and adoption may also mean that cost-reducing technological change may be beneficial to the agricultural sector compared to output-increasing technological change. The farm sector, as argued earlier, will increase output if costs of production are decreased. However, this adjustment process entails intermediate reactions which may lead to output increasing at a lower rate than what would occur with output-increasing technological change. The result may be greater profits for more farmers for a longer period of time.

V. The Impacts of Plant Biotechnology

A few years ago it was generally acknowledged that the technology to work with plants was not well developed. The genetic structures of few plants were known and the techniques to modify plants were not readily available. Yet, the 1984 OTA report on biotechnology stated that developments in the plant area were imminent. Since that time advances have been made in plant technology and significant advances will occur in the near future (Moffat). Although the commercial development of products in the animal area may still be ahead of plants, that lead is not to the extent thought just a few short years ago. Nonetheless, it is still true that the technology to work with the economically important monocots, such as the cereal and feed grains, is still behind the work on the dicots.

The commercial potential in the plant area includes herbicide resistance, pest resistance (insects, viruses, fungi, etc.), enhanced products, improved characteristics, nitrogen fixation, and photosynthesis enhancement. Some of these changes, such as nitrogen fixation in grass, are considered to be many years down the road, and commercialization is well into the next century. However, major breakthroughs and enhanced research efforts may speed up the development. Other products, such as resistance to specific herbicides, are technologically feasible now and commercialization may be by the next decade.

Very little economic research has been completed to date to analyze the potential economic impact of improved plants from the applications of biotechnology. Most efforts instead have concentrated on estimating time lines to development or commercialization (Farrell and Funk), or the consequences of property rights in plants (Schmid). The work by Rosegrant, Roumasset, and Balisacan with Azolla in rice production and other plant economic research (Sundquist, et al.) borders on the areas of biotechnology, and recently Hill, et al., have discussed in an exploratory manner the nitrogen technologies. Yet, if the results obtained from the animal growth hormone research are any indication, the economic impact of much plant biotechnology could be significant.

Herbicide resistance may be the first commercially available plant product. Some question the wisdom of this research since the resistances that will be conveyed may be for herbicides that are toxic and persistent. Many have patents that have or will soon expire. It is an attempt to breathe new life into these chemicals at a relatively low cost. The result will be increased use of these chemicals (although some argue ineffectively otherwise), when more effective, less toxic chemicals can be developed. If the externality cost of pollution and health can be captured, the true social cost could be greater than the benefit. However, this is a simplistic, inadequate assessment of this research, resulting from looking at one product in isolation. Herbicide resistance is also being conveyed for what are considered fairly safe, yet effective herbicides. These will replace the more toxic herbicides since they are more effective and will not be banned. The science learned in this whole area will also allow us to design more effective, safer herbicides, and has tremendous scientific value even if specific products are not commercialized.

Although direct nitrogen fixation by grains, or even the development of a symbiotic relationship between nitrogen fixing bacteria and grains as exist in legumes, is considered by most to be beyond this century, enhancement of the current symbiotic relationship between bacteria and legumes (and other plants) by biotechnology is considered almost a certain development. Direct nitrogen fixation by grains may reduce the demand for applied nitrogen, but increasing the ability of Rhizobia to fixate nitrogen with legumes would clearly reduce applied nitrogen.

It is almost universally believed that direct or symbiotic nitrogen fixation with grains will require energy from the plant and reduce yields. The development of this technology would provide farmers with two concurrent nitrogen technologies/practices. They could either utilize the nitrogen fixation version of a variety and save the cost of the purchased nitrogen and suffer the reduced yield, or stay with their current practice of applying nitrogen. The economic decision is predicated on whether the value of the applied fertilizer saved is greater than the value of the yield reduction plus the cost of the nitrogen fixation version of the seed. If may be that fertilizer or the seed will be priced as necessary to maintain itself as an economically viable alternative. Although nitrogen production facilities and seed research both have sunken costs, it would be optimum for the seed companies to price their seed so that fertilizer would have to be priced below marginal cost, shutting down nitrogen production. The externalities of pollution from applied nitrogen may swing the decision if those costs are internalized to farmers or nitrogen producers through conservation regulations or an input tax.

Improving the nitrogen fixing abilities of bacteria symbiotic with legumes would reduce the need for applied nitrogen for grains grown in rotation. The current rule of thumb is that a pound of available nitrogen is made available to corn for every bushel of soybeans produced the previous year (Aldrich). Increasing that yield to two pounds could have a significant impact on nitrogen purchases. Assuming a yield of 40 bushels of soybeans, an additional 40 pounds of available nitrogen would be available for corn the next year. Using the economic model of Beattie, Thompson, and Boehlje, it is clear that a farmer would grow more soybeans to rotate with corn. That would result in an increased aggregate supply of soybeans and a reduction in corn, with corresponding price changes. However, if need for higher protein rations results from the animal growth hormones and other repartitioning agents simultaneously, price changes may be muted.

As in nitrogen fixation, it is not clear that plants can be genetically enhanced without a yield reduction. Drought resistance may be engineered into a plant but at the cost of reduced yields during normal precipitation. With a sufficiently high probability of drought, however, the expected yield may be increased as well as the yield variability reduced. This indeed would be a first degree stochastic efficient improvement and thus preferred by any farmer who prefers higher yields (Meyer). In other cases expected yield will be lower, but the improvement would reduce yield variability and be desired by those sufficiently risk averse.

The production of enhanced or new proteins from plants is especially exciting because it entails an increase in the demand for a crop. With inelastic demand, revenue would increase. However, the demand for other agricultural commodities may diminish leading to little overall aggregate impact on agriculture. What is necessary is to find non-food uses for agricultural products (i.e., plastics from corn). Whether those new products are produced with plants rather than some chemical or fermentation process would depend upon the competitive economics involved. Even chemical and fermentation processes need feedstock and it may be more economically efficient to let the plants produce the final product rather than the feedstock material.

Another area of immense interest is the production of plant products of economic value from the test tube, or more correctly from vats. Development here is in its infancy and the control mechanisms are not understood. Obviously additional time and research effort may allow the production of orange juice or cotton fiber in manufacturing plants (Flynn). What is often ignored in these statements is economic feasibility. The production of cells requires nutrients and energy. Plants growing in farmers' fields may be more economically efficient than fermentation or cell culture vats. At the least we would still expect that farmers would be growing biomass for their local agricultural manufacturing plant. Of more value from these new cell culture abilities may be the opportunity to observe genetic changes on a plant product (cotton fiber) before injecting the genetic material into various varieties and field testing.

John Love and I recently looked at the economic effects of reducing viral disease losses in U.S. potato and tomato production. Although virsus do cause yield reductions in field crops, our search through the yield loss assessment literature did not find estimates close to the 10 percent losses reported by Florkowski and Hill in their survey of the experts. We suspect they surveyed the scientists in the forefront of the new science who either do not have sufficient knowledge of field losses, or who are biased by their optimism of the economic importance of their work as others have observed (Hutton). It appears however, that annual virus losses in potatoes and tomatoes average about 5 percent.

Using published own-price and cross-price demand elasticities, and supply elasticities, we shifted the supply curve parallel by 5 percent for fresh and processed potatoes and tomatoes. The impacts ranged from a market clearing quantity increase of only .2 percent for processed potatoes but a price decrease of 24 percent, to a quantity increase of 2.4 percent for processed tomatoes with a price decrease of 9 percent. Total economic surplus increases, ignoring research costs, ranged from 2.6 to 5 percent indicating society would be better off with a virus free potato or tomato.

VI. The Impacts of Bovine Growth Hormone

We have completed economic research on the potential economic impact of bovine Growth Hormone (bGH) or Somatotrophin on New York dairy production. Approaches entailed shifting an aggregate production function (Magrath and Tauer, 1986a) and mathematical programming (Magrath and Tauer, 1986b; Tauer).

Since only the state of New York was modeled in these efforts, we assumed that the state's market share of the national milk market would remain constant if milk output either decreased or increased, although some have presented results showing regional shifts in production (Boehlje and Cole).

Since the field (farm) response to bGH is not yet known, we analyzed various levels of response per cow from 10 to 30 percent (annual). In one paper we even assumed differential responses by farm productivity (Magrath and Tauer, 1986a). In the programming models, hypothetical optima feed rations with bGH were used (Kalter, et al.), and were tailored to cow production levels. Crop budgets were generated for seven land qualities for corn grain and silage and hay. In one approach whole representative farms were formulated (Tauer).

The results can be summarized with some general statements concerning the economic impact of bGH. First, the aggregate increase in milk output with market clearing prices is only about a third of the average response per cow as farmers respond to lower milk prices. Thus a 20 percent increase at the cow level translates into only a 7 percent aggregate increase in milk. However, the milk price decrease will be about the same as the percentage increase in output per cow because the demand elasticity for milk is about -.3. Thus a 20 percent increase in milk output per cow will result in about a 20 percent decrease in the market clearing price for milk.

If milk price supports are not adjusted downward with the introduction of bGH, milk output would increase tremendously, the only effective constraint being how quickly farmers can add cows. Our results also indicate that given less than a 20 percent per cow increase, an adoption rate estimate by Kalter, et al., and a government milk program that has balanced supply and demand by the time of bGH commercialization through complete adoption, the introduction of bGH would not traumatize the dairy industry. The impacts of simply balancing milk supply and demand before bGH is introduced could be more significant. The reason for the reduced impact of bGH is that its profitable use at lower milk prices is greatly reduced. At 25 cents a daily dose, only farmers with high production herds may find it marginally profitable to use.

The introduction of bGH could also have significant impacts on land usage and values. In the short run high quality land may increase in value until the industry approaches equilibrium since a premium will be placed on the high quality forage produced on that land. There may be a tendency for farms with low quality land resources to remain in the industry in the short run until they delete their cash reserves. In principle, bGH is size neutral except to the extent that higher producing cows and better farm managers are associated with larger farms.

VII. Conclusions

Economic research on biotechnology in agriculture is challenging since very little concrete information is available concerning the impact that these new products and processes will have on agricultural production. It is necessary to work closely with the biological scientists in order to model plausible production scenarios and to perform sensitivity analyses to determine if results are robust.

I argue that there may not be much difference between cost-reducing verses output-increasing technological change, except to the extent that farm adjustments do not occur instantaneously. I also argue that continuous technological change results in excess resources in agriculture, which generate lower average rates of return than what would exist under no technological change. The distribution of those returns is much greater with continuous technological change, presenting early continuous adopters with greater returns than would exist under no technological change.

The impact of plant biotechnologies will be varied depending upon the product. Producing virus free potatoes and tomatoes, for instance, will increase total social surplus by 2.6 to 5 percent. Other plant products could have more significant impacts. Our research results on bGH suggest that product may not have a significant impact on dairy production if milk production is balanced with demand before and during the introduction of bGH. In fact, depending upon the price of bGH, low and even average producing herds may not find bGH to be a very profitable input.

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