WESTERN AGRICULTURAL ECONOMICS ASSOCIATION

PAPERS OF THE
1989 ANNUAL MEETING

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ECONOMICS ASSOCIATION

COEUR D'ALENE, IDAHO

JULY 9-12, 1989

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PREFACE

At the 1988 annual meeting of the Western Agricultural Economics Association, the members voted to have invited, selected and association business papers copied for distribution at registration of the 1989 meetings. This collection of papers represents a copy process to make available to meeting participants copies of papers being presented at the meetings. The purposes are to enhance discussion in paper sessions and to permit participants to gain from presentations they are unable to attend. This booklet is a copy service which does not represent publication. This booklet is unedited and the authors have not received the benefit of referee comments.

Marc A. Johnson
WAEA Vice President

Understanding the Possible Economic Effects of Technological Change: Efficiency, and Distributions of Benefits and Costs

Russell L. Gum
William E. Martin

Introduction

The future of biotechnological development, or genetic engineering, is generating much public discussion. The discussion centers on the immense potential to make improvements in human welfare through appropriate use of genetic engineering versus the immense potential to make the human condition worse off through inappropriate use or because of unexpected side effects. In this paper we only briefly mention the range of themes involved in the current public debate before discussing the issue from strictly an economists' point of view. Our rationale for emphasizing this view is that unless the economic potential is satisfactory to society, the potential negative effects of technology adoption are irrelevant. Our examples of economic impacts are restricted to innovation in agriculture.

Risk

Development of any new technology has elements of risk arising from the new and partially unknown aspects of the technology. One only has to think of the example of "killer bees", which resulted from lack of sufficient controls on a relatively simple bee breeding experiment, to realize that the possibility exists for serious mistakes caused by biological science gone awry. Biotechnological development of plants and animals potentially is a much more powerful tool than traditional breeding, so one might suspect that the possibilities of major problems being caused as a result of biotechnological accidents are real. The extreme care exercised in controlling the testing and commercial introduction of the products of biotechnological research is an indication that the possibilities for accidents have been recognized.

Moral Issues

The development of organisms with genetic material from multiple species has led to charges that biotechnologists are playing God. Some people feel that such scientific alterations should not be permitted for any species. Others speculate on whether or not such procedures might or should ever be used on humans. Certainly the role of science in determining the genetic makeup of species has the potential to become political and religious issues.

Role of Universities

Much of the research on biotechnology currently is being done in public universities with public funding. In addition to the issues of risk and morality, the relationship

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between university scientists doing biotechnological research and the private sector is becoming a political issue. How the costs and rewards of biotechnological research and innovation should be distributed? Should the public pay for the costs of discovering and developing commercially viable products and then have the scientists hired away by the private sector, or should some more equitable partnership between private and public institutions be developed?

Economics

While the issues of risk, morality and the relationship between universities and the private sector are real, and increasingly being discussed in the political arena, they simply do not matter if biotechnology does not have the potential to be valuable in terms of economic results. If biotechnology cannot produce economically useful products, the pressure to solve the political problems associated with the risk, morality, and public versus private issues will be minimal.

The purpose of this paper is to look critically at the issues of determining and projecting the potential economic impacts of biotechnology. Clearly, most changes will produce both winners and losers – at least in the short run. A few changes may even produce all winners. Understandings and misunderstandings about the magnitude of the impacts and the probable distributions of winners and losers are the bases of arguments about the economic benefits and costs of technological development policies.

The lay public, which includes most agricultural scientists and administrators as far as economic understanding goes, tends to rather simplistic views. The complex adjustments in prices and quantities resulting from technological change in one economic sector or region are rarely recognized, much less quantified. In our experience with biotechnologists, many believe that increased production clearly is a general benefit to the farm sector in questions, while a few believe that increased production clearly will be a disaster as overproduction causes prices to plummet. The expected results are black or white - not grey - and the effects on other sectors of the economy are rarely recognized.

Agricultural economists have not done as much as they might have to remedy these simplistic views. Traditionally, we have concentrated on effects on agriculture, and usually on effect on a particular agricultural production sector. Schmitz and Seckler (1970) were pathbreakers in including other sectors, in their case labor, in their benefit cost analysis of mechanizing tomato harvesting. Since that time the development of welfare economics and the wider understanding of economists of the concepts of producers' and consumers' surplus has led economists to consider both producers and consumers, but the more intricate effects of change on the total economy still have not been well communicated to the noneconomist scientific community.

Such communication is very difficult because understanding of the possible relationships is difficult. General equilibrium models are extremely complex. Even among economists most economic discussions of policies are based on generalized results in the context of simple partial equilibrium theory. This partial view of the economy grossly neglects the complex effects that could occur in a dynamic equilibrium economy. This paper (and the three associated papers in this session) attempt to illustrate the possible complex economic effects of technological change in a way that can be understood by a scientific lay audience. In doing so, we concentrate on the distribution of benefits and costs under alternative supply conditions.

Definition of Economic Impact

Economic impacts of a technological change can be best defined in terms of changes in real income to consumers and changes in profits to producers. At the individual producer level the net benefits are the change in the difference between gross returns and variable costs. This measure of profits can be considered the returns to the fixed factors of production such as land, the physical facilities, and management. It is formally known as producer's surplus. For the consumer the net benefits may be estimated in three alternative ways. First, there is the maximum amount of income that they could pay for the technological development, and be just as well off as they were before the payment and the technological change. This measure is known as compensation variation. Second, there is the minimum amount of additional income they would have to receive to be just as well off as without the technological change. This measure is known as equivalent variation. It is somewhat larger than compensating variation. Finally, there is a measure lying between these two values known as consumer's surplus. The specific measure used will vary depending on both conceptual circumstances and ease of estimation. The aggregate of the increase in consumers' and producers' welfare is the measure of the economic efficiency of a technological change. The larger the net increase in the sum of consumer and producer benefits, the more efficient the technology. However, in addition to the total economic impact, the distribution of impacts is also relevant. Some groups will be winners while others are losers. Society might prefer lower total benefits in favor of an alternative distribution of benefits. We attempt to deal with both the efficiency and distribution components of the economic impact of biotechnology.

Adoption of Biotechnology

Adoption of a new technology in the agriculture sector will by a few innovative firms, followed by adoption by other firms if the new technology proves profitable. The adoption rate typically may be described by a sigmoid curve. Initially almost all of the economic impacts are concentrated in the increased profits of the early adopting firms. As more and more firms adopt the technology, the economic impacts become more complex as changes in profits lead to changes in quantities supplied and resulting changes in both product and input prices. These price and quantity changes in the agricultural sector in turn have indirect impacts in the remainder of the economy. After initial adoption, impacts may be either positive or negative in any of the sectors involved.

Policy Analysis

To correctly identify and project these economic impacts as they ripple throughout the economy is the basic task necessary for making an accurate assessment of the economics of possible biotechnological innovations.

The simplest view of technological change is to look at a budget for a producer and determine the change in profits of adopting the new technology holding everything else, including product and factor prices and government programs, constant at current levels. This procedure leads to the conclusion that increased production without increased costs will be of benefit to the adopters and neither benefit nor harm any other sector, including consumers.. Such an approach completely ignores the interdependence of the different sectors in a dynamic economy and is only correct for the initial stage of technology introduction where only a few innovative firms are using the improved technology. Such an approach is a serious misstatement of the facts, and besides being economic nonsense, has resulted in the past in an incorrect public perception of who benefits from technological change.

A slightly more sophisticated approach is to recognize the relationship between quantity supplied and price. Using the paradigm of partial equilibrium allows consideration to be given to both consumers and the directly affected producers, but does not consider impacts in other markets. Such a paradigm leads to the public perception that technologies which increase production will cause prices to fall and will not be of benefit to producers. The implications of who benefits has shifted to the consumer, with the producer facing the possibility that prices will fall faster than costs, resulting in a reduction in profits.

A more realistic approach is to recognize the interconnection of the markets for goods and inputs in the agricultural sector and introduce the possibility that a change in the production process for one commodity may have impacts on the production and ultimately the price to consumers for all agricultural products.

The most realistic approach would be to recognize the interconnection between all sectors of the economy and attempt to estimate the impacts of biotechnology innovations in the specific agriculture sector on every production and consumption sector of the economy. Carried to the absurd, estimates could be made of the impact of a change in cotton production technology in Arizona on the price of tea in China.

Since the costs of economic analysis are not zero and well tested accurate general equilibrium models do not exist, the selection of appropriate procedures for the economic analysis of biotechnology is not a trivial problem. Clearly the simple budgeting of individual firms, holding all prices constant, is not appropriate. The real question comes down to choosing between partial equilibrium models and agricultural sector models which have some of the characteristics of general equilibrium models. The choice must be made on the trade-offs between the costs and complexity of the analysis, the accuracy of the analysis in terms of efficiency related welfare measures, and the accuracy of the estimates of the distribution of impacts among sectors of society.

Economic logic suggests that partial equilibrium approaches will result in incorrect estimates of the economic impacts of biotechnology as they do not consider the complex adjustment process which occurs in agriculture when major changes in the production process result in changes in relative prices among outputs and inputs. Limited research on the differences between the results of partial equilibrium models and general equilibrium models empirically document that major differences in welfare measures can exist in results from analysis using partial as opposed to general equilibrium models. See Whalley (1975), Edlefsen (1983), and Kokoski and Smith (1987).

Distribution of Impacts

The distribution of impacts should be a major part of any economic analysis on the benefits and costs of a technological change. The design of economic analysis to account for distributional impacts must consider several major problems. First, since it is impossible to develop measures of gains and losses for each individual impacted either directly or indirectly by the technological change, a reasonable grouping of individuals is necessary to allow the measurement of gains and losses by groups instead of by individuals. The selection of these groups has both political implications and implications for the form of the economic analysis. Our analysis defines groups in terms of producers of particular commodities and consumers as a whole.

Once the groups have been defined and the impacts calculated for each group, a decision must be made whether simply to report the results for each group, or to find a meaningful way to summarize the distributional impacts in addition to reporting the raw results. We suggest the following index as a reasonable way of summarizing the distribution of impacts:

I = net benefits / total positive benefits.

Table 1 presents both raw distributions and the summary index for two hypothetical technological innovations. Both alternatives result in net benefits equalling 200.

In the first example an amount equal to 50% of the net benefits is transferred from losers to gainers. In the second case a transfer of only 9% of the net benefits is made. Obviously, the distributional impacts in the second case are less severe than in the first.

The index will equal 1 for the case where there are no losers and will approach 0 for the case where there are large transfers and small net benefits. A negative index is possible if net benefits are negative. Because of the existence of a Pareto optimum when the index equals 1, (that is, when some groups gain and no group loses), we term this measure the index of paretoality.

Economic Analysis

The approach taken in this paper is to attempt to illustrate the possible economic effects of technological change using a range of economic techniques in a way that can be understood by a scientific lay audience. We start with a simple abstract model to illustrate the basic concepts involved in such an analysis and then proceed to use two empirical models of the U.S. agricultural sector to analyze possible biotechnological changes. Finally we conclude with a discussion of the general conclusions we can draw from our analysis and give our recommendations about techniques that should be used in future studies of the economics of biotechnology.

A Basic Illustrative Model

Assume a completely competitive economy where instantaneous market equilibrium applies. As a first approximation to a completely general equilibrium model where everything is endogenous, we have devised the following three-good model which allows us to illustrate the complexities of market equilibrium systems. A market equilibrium system is defined as a system where consumers and producers simultaneously interact to determine the quantities and prices of goods to be produced and consumed.

We take it as an axiom that the consumption by people is the driving force in a market economy. They wish to maximize their utility. They do so simultaneously with producers attempting to maximize their profits subject to the resources and technology available to them, which can be expressed as their supply functions. The supply function is the locus of profit-maximizing points of producers, given changing demand. Of course, producers are also consumers.

Our simple generic model maximizes consumers' utility, subject to producers' maximizing profits (operating on their supply function), and a consumer income constraint. The assumptions of this model are that (1) all consumers have the same utility functions, (2) producers maximize profits in response to consumer actions and their resource and technology constraints, and (3) consumer income is not related to producer profits. This model is not a completely general equilibrium model particularly because of assumption number 3. However, it is a useful intermediate step between partial equilibrium and general equilibrium analysis. We believe that the model is a reasonable approximation of an economy consisting of an agricultural sector which is a small component of the total economy, if what are varied are agricultural technologies. Thus, consumer incomes in general are not directly related to agricultural incomes.

Consider the following model of consumer utility.

$$U=Q_1^{0.5}(Q_2+Q_3)^{0.3}$$

where:

U is a measure of an individual's utility.

Q_i is a measure of the quantity of good i purchased and consumed.

One may consider Q_1 to represent all nonagricultural goods and Q_2 and Q_3 to represent agricultural products. The structure of the utility function implies that Q_1 is a complimentary good to both agricultural goods, while Q_2 and Q_3 are perfect substitutes. Utility is a function of the level of all nonagricultural goods times a function of the sum of all agricultural goods.

The logic of the model is that for agricultural goods there are many ways to meet the equivalent levels of quantity and quality of one's diet. Levels of quantity and quality of diet will interact directly with nonagricultural goods to determine utility. A high level of quantity and quality of diet and a low level of other goods (or vice versa) imply a lower level of utility than moderate levels of both.

The sum of the exponents on the Q's of the model implies that a doubling of the goods available to be consumed results in less than doubling of utility. That is, decreasing marginal utility of goods is implied.

Goods are produced for consumption according to the following three supply functions, representing the given technologies and resource endowments:

$$Q_1 = a_1P_1^{b1}$$
$$Q_2 = a_2P_2^{b2}$$
$$Q_3 = a_3P_3^{b3}$$

The functions reflect the assumption of increasing marginal costs of production, that is, $O<b_i<1.0$. As a result of increasing marginal costs, doubling of price results in less than a doubling in output.

Consumer income is assumed constant at K per capita. This simplifying assumption reflects the fact that most consumers' incomes are not related to producer profits, at least in the short run.

What can we learn from operation of this simple model relative to biotechnology policy? By definition, any improvement in production technology lowers the cost of production for a given quantity of output, and, simultaneously, increases quantity of output for a given cost. This definition implies that any technological improvement will result in a downward shift in the supply curve–more goods being produced for the same price. While this result might appear as a no-lose situation, in fact, there can be both winners and losers because of the market interactions in a general equilibrium economy.

While consumers in general will always win with a technological advance (assuming a competitive economy–the conditions of our model), some producer groups may win and others may lose. It is possible for technological improvement to result in benefits for all groups, or in major negative impacts on some industries with major benefits for others. This model has been devised to illustrate these alternative results. In addition to the politically sensitive issue of distribution of net benefits, there is the economic issue of the total quantity of net benefits, i.e. the economic efficiency issue.

Net benefits of a technological change for consumers are defined as the minimum amount of additional income they would have to receive to be just as well off as without the technological change; that is, equivalent variation. Net benefits for each producer group is the difference between gross returns and variable costs – the measure of producers' surplus.

These measures are computed as follows. First, consumer utility is maximized given the original income and supply function constraints. The results give a level of utility, and a set of prices and quantities of each good produced and consumed. Producers' surplus for each group of producers is calculated as the difference between gross returns (price times quantity) and the area under the supply curve, which is equal to total variable cost.

A technological advance is introduced into the model by changing either of the coefficients on one of the supply functions, shifting the function downward and to the right. The model is re-solved. The results are a higher level of utility and a new set of prices and quantities, and associated producers' surpluses. The changes in producers' surpluses are computed. The new level of utility is substituted back into the original model as a restraint, and the model is re-solved by minimizing the level of income necessary for consumers to reach this level of utility. The additional income above the original income constraint is the equivalent variation generated by the technological advance. Total net benefit to society is the sum of the change in equivalent variation and the changes in producers' surpluses. While the change in equivalent variation is always positive, the changes in producers' surpluses may be either positive or negative.

Even with such a simple model, the nature of the results will differ depending on how and by how much the supply curve shifts, and by whether demand intersects the supply curve at a lower or upper level of the curve. [Miller, Rosenblatt, and Hushak (1988) recently have demonstrated mathematically "that for general convex supply curves, ...the major determinants of changes in producers' surplus are the relative slopes of the supply and demand curves at equilibrium and not the elasticities of supply and demand" (p. 891).] The supply curves are of the form $Q = a P^b$. Along any given curve there is constant supply elasticity equal to the value of b. Thus, a 10 percent change in price will result in b times a 10 percent change in quantity supplied. If the exponent b is reduced, the supply curve will be lowered at all points up to quantity a. See curves S_1 and S_2 in figure 1. The quantity a^0 is assumed to be the maximum possible quantity of that good that the economy can produce. This assumption is enforced by restricting all prices to be less than 1. The technological advance implied by reducing the coefficient b, reduces the cost of production of all quantities up to the maximum caused by some resource limit a^0.

Alternatively, technological change can be thought of as increasing resource limits. This can be reflected in our model by increasing coefficient a^0 to a^*. See S_3 in figure 1. Curve S_2 has a lower constant elasticity than curve S_1. Curve S_3 has the same constant elasticity as curve S_1.

In addition to how we view technological change shifting supply functions, the nature of the results depends on the slopes of the supply curves where they are intersected by demand. When the supply curves are steeper, changes will be reflected more in consumer price than in quantities demanded. With flatter supply curves the technological change will be reflected more in quantity demanded than in price.

Technological change is not likely to occur without cost; research expenditures to develop the technology and extension expenditures to promote adoption will be required. Much of technological change in agriculture occurs as a result of public funding of the Land Grant System of Agricultural Experiment Stations. The consumer, rather than the producer, is funding much of the development. This fact can be reflected in our model by subtracting a contribution to R and E expenditures from the consumers' income constraint, i.e. I = K - R and E.

Operation of the Basic Models

Ruttan argues that a certain amount of R and E expenditure is necessary just to keep agriculture supply functions constant. Thus the models illustrated in this paper assume the income constraint to be I = 10,000 - 100, where the 100 are R and E expenditures necessary to maintain current productivity. These expenditures are paid for by the consumer, but the technological change itself is achieved without additional expense. Clearly additional R and E expenditures actually would be required. Since consumers are always the beneficiaries of technological advance, it would be useful to inquire how paying for the technological advance would affect their utility. The model is structured so that this inquiry may be addressed by increasing the R and E expenditures, but those models are left for another paper.

Model A

In this model the a coefficient for all supply curves is set at 100,000 units. The b coefficient, that is, the elasticity of supply, is initially set at 0.5 for all supply curves, and then iteratively lowered from 0.5 to 0.1 for the commodity Q_2, causing that supply curve to shift to the right, Since R and E is held constant at 100, the technological change in this model is assumed to have occurred without additional R and E cost. All producers of commodity Q_2 immediately adopt the new technology, and adjustments are instantaneous.

The results are show in table 2 and figure 2. The sum of quantities of Q_2 and Q_3 purchased by consumers interacts with purchases of Q_1 to determine consumers' utility. The quantities produced determine the prices. The interaction of these phenomena determine equilibrium at maximum consumer utility, consistent with producers maximizing profits.

With each downward shift of this supply curve for commodity Q_2, consumers' total utility rises. The quantities of Q_2 produced are larger and its price in lower. Because Q_2 and Q_3 have been defined as perfect substitutes, and they have identical initial supply functions, initially consumer utility is maximized where equal quantities of Q_2 and Q_3 and produced and sold at the same price per unit.

But as the supply curve for Q_2 begins to differ from that of Q_3, becoming lower and flatter, consumers are able to make marginal adjustments in the consumption of all three commodities that will further increase their total utility (figure 2). As the price of Q_2 falls, Q_2 is substituted for Q_3 and the price of Q_3 also falls. A partial equilibrium, two-good analyses, might suggest that because Q_2 and Q_3 are perfect substitutes to the consumer, that the price of Q_3 would fall to equal that of Q_2 at the new equilibrium. Such is not the case. Because consumers also have the opportunity to purchase extra quantities of Q_1 with their newly freed-up income, and because Q_3 no longer has an identical supply function to Q_2, consumers maximize utility by increasing consumption of Q_2 greatly, decreasing consumption of Q_3 only slightly, and spending more on Q_1. The price of Q_3 falls, but not to the level of P_2. The price of Q_1 is driven up by the increased consumption.

This three-way adjustment is possible because in the vicinity of the equilibrium solution, the supply curve for Q_3 is steeper than for Q_2. A relatively small cutback in consumption of Q_3 frees up enough income to satisfy the desire for more Q_2, as well as allowing more consumption of Q_1.

How have net benefits been affected by these changes in prices and quantities? See table 2. Equivalent variation (EV) for consumers rose from zero to 10,377. They are now as well-off, after the technological change and the resulting consumption adjustments, as they would have been without the change and adjustments and had an income of 20,377.

Producers of Q_2, the group experiencing the technological change, first earn additional profits but then suffer loses as the change becomes more drastic. The change in producers' surplus ΔPS_2) rises from 0 to 390 and then falls to minus 298 as the b_2 coefficient moves from 0.5 to 0.3 to 0.1. Given that nominal aggregate consumer income has not risen, and that the basic utility function has not changed, producers of Q_2 would gain from a relatively small technological change, but lose with a large one.

Producers of Q_3, the substitute good, would lose with technological change in the production of Q_2. ΔPS_3 continuously falls from 0 to minus 432 as cost of production of Q_2 becomes less and less. Producers of Q_1 continuously gain. As less income is needed for food consumption, all other goods are purchased in greater quantities.

Producers in total (ΔPS) gain under all posited technical changes, but are better off in total with the medium level change. Total net benefits to society in general (EV + ΔPS) increase with each posited change.

Alternative Models

Six alternative models were evaluated as summarized in table 3. In each model, technological change was expressed through the supply function for Q_2 in a slightly different way or in slightly different circumstances relative to the supply curves for Q_1 and Q_2.

The most general conclusion is that consumers will always benefit from technological change in a competitive market society. Equivalent variation–the equivalent amount of income that they have gained by the technological change is always positive. In our models, producers in general (ΔPS) and society in general (TNB) also always have positive net benefits. The sum of gains outweigh the sum of loses. One can imagine constructing a model where producer losses to one group of producers are so large that they outweigh gains to all other producer groups, but it is difficult to imagine such a situation in real life. It is even harder to imagine a scenario where net loss to society in general would occur, given that consumers will always have gains. It is the distributive issue of gains and losses among producer groups that is at issue.

Models A through C illustrate that when technological change in agriculture is effected only by lowering the elasticity of supply, and not by increasing the total productive capacity for that product, producers outside of agriculture (ΔPS_1) are likely to be beneficiaries. The producers experiencing the technological change (ΔPS_2) are likely to be losers if they are operating near an ultimate resource constraint near the top of this supply curve. If their initial position is back on the supply curve in a relatively low-cost area, some technological change would create gains, but too much change, without growth in the overall economy, would create losses. Producers of Q_3, the substitute good, might either lose, gain, or be unaffected, depending on whether their supply curve was steeper, flatter, or of about equal slope, respectively, of the supply curve for Q_2.

Models D through E_1 illustrate cases where supply elasticities remain constant while the technological advance increases the maximum resource constraint. In these cases the group experiencing the technological change is always a gainer and the producers of substitute goods are losers. Producers of the nonsubstitute goods may be gainers, losers or unaffected depending on the relative values of the various supply elasticities.

Also shown in table 3 are the ranges in the Index of Paretoality (IP) for each model as the supply curve representing the technological advance shifts downward from the base. Examine the indices for Model C. With a small downward shift in the supply curve for commodity 2, producers of commodity 3 experience no effects, and all other producer and consumer effects are positive. Thus, IP equals 1.00 when computed either for all sectors (consumers plus producers) or for producers only. If the supply curve for commodity 2 is lowered substantially (from $b_2 = 0.5$ to $b_2 - 0.1$), IP equals 0.87 for all sectors and only 0.30 if only producers are considered. An IP of 0.30 means that only 30 percent of total positive benefits occurring because of the technological advance are net benefits. That is, for every dollar of benefits generated in other producing sectors by the technological change in sector 2, sector 2 experienced $0.70 of loss.

Summary

This paper has presented a brief introduction to a way in which the potential complexities of the effects of technological change can be illustrated to a noneconomist scientific audience. There will always be a distribution of relative winners and losers. Who these winners and losers will be, and what the magnitudes of the wins and loses will be, are not usually apparent before the technological change is adopted. Partial equilibrium analysis, using available supply and demand elasticities are unlikely to express the real a posteriori condition. The presented model is only an introduction. It may be expanded in a number of ways. Two other ways in which we have used the model are to examine the effects of R and E expenditures on the distribution of benefits and losses, and to look at different rates of technological adoption between regions.

Clearly estimation of the real effects is an empirical general equilibrium problem, rather than either a theoretical problem or a partial equilibrium problem. The authors are cooperating with a number of colleagues in the use of large-scale national econometric and mathematical programming models in an attempt to evaluate empirically specific technological changes in agricultural production in the context of the national and international economies. These models capture much complexity empirically, although they are not general equilibrium models in that they focus mostly on only the agricultural sectors.

Short descriptions of two of these empirical models follow in the next two papers, with presentation of the empirical results in a concluding paper. Whether these empirical models generate credible predictions also is a matter for discussion. Our conceptual illustration gives us the insight to expect unexpected results whether or not these empirical models are in fact true reflections of reality.

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Table 1. Hypothetical Distribution of Benefits Resulting from Two Alternative Technological Innovations.

Group and Results	Change in Benefits	
	Innovation 1	Innovation 2
Consumers	+ 200	+ 200
Producers of good 1	+ 100	+ 10
Producers of good 2	+ 100	+ 10
Producers of good 3	- 200	- 20
Net benefits	200	200
Total positive benefits	400	220
Index	0.50	0.91

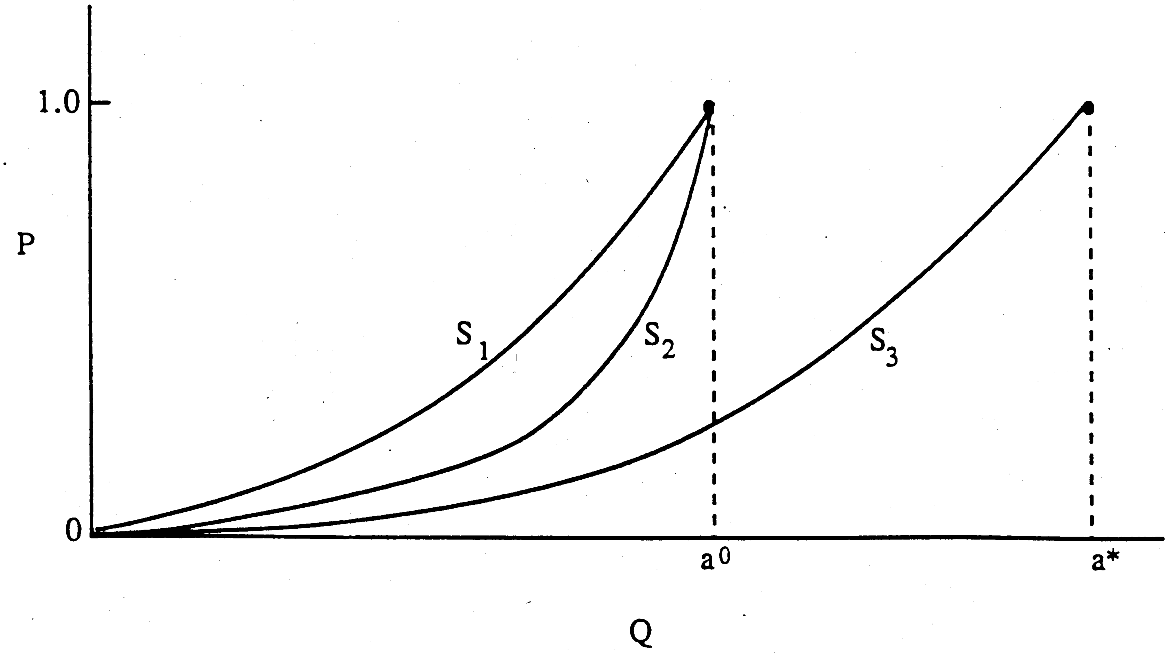

Figure 1. Alternative Supply Curves in the Models

Table 2. Model A: Solution of the General Equilibrium Model as a Technological Advance Occurs in the Production of Good Q_2 (a_i= 100,000; $b_i = b_3 = 0.5$; b_2 is varied; research and extension expendure are held constant)

a_i	b_2	R&E	U	Q_1	Q_2	Q_3	P_1	P_2	P_3	EV	ΔPS_1	ΔPS_2	ΔPS_3	ΔTotal PS	Total Net Benefits
100,000	0.5	100	5,197	39,552	26,478	26,478	0.16	0.07	0.07	0	0	0	0	0	0
100,000	0.4	100	5,356	39,950	31,786	25,779	0.16	0.06	0.07	1,181	126	325	-95	355	1,536
100,000	0.3	100	5,567	40,525	38,969	24,987	0.16	0.04	0.06	2,913	312	390	-197	505	3,418
100,000	0.2	100	5,860	41,367	49,247	24,069	0.17	0.03	0.06	5,628	594	186	-308	472	6,101
100,000	0.1	100	6,292	42,640	65,419	22,944	0.18	0.01	0.05	10,377	1,044	-298	-432	313	10,691

Table 3. Summary of Net Benefits or Losses to Consumers and Producers; Models A through E.

								Index of Paretoality	
Model		EV	$\Delta PS1$	$\Delta PS2$	$\Delta PS3$	ΔPS	TNB	Consumers & Producers	Producers Only
A	$a_i = 100{,}000$; $b_1 = b_3 = 0.5$; b_2 varied	+	+	±	–	+	+	0.94 - 0.94	0.79 - 0.30
B	$a_i = 7{,}500$; $b_1 = b_3 = 0.5$; b_2 varied	+	+	–	+	+	+	0.99 - 0.86	0.97 - 0.27
C	$a_i = 10{,}000$; $b_1 = b_3 = 0.5$; b_2 varied	+	+	±	0	+	+	1.00 - 0.87	1.00 - 0.30
D	$a_1 = a_3 = 10{,}000$; $b_i = 0.5$; a_2 varied	+	0	+	–	+	+	0.91 - 0.94	0.64 - 0.57
D_1	$a_1 = a_3 = 10{,}000$; $b_2 = b_3 \neq b_1$; a_2 varied	+	0	+	–	+	+	0.90 - 0.93	0.64 - 0.55
E	$a_1 = a_3 = 10{,}000$; $b_1 = b_2 = 0.5$, $b_3 = 0.3$; a_2 varied	+	–	+	–	+	+	0.91 - 0.93	0.67 - 0.59
E_1	$a_1 = a_3 = 10{,}000$; $b_1 = b_2 = 0.5$, $b_3 = 0.7$; a_2 varied	+	+	+	–	+	+	0.90 - 0.93	0.61 - 0.55

[a] Range of the index as the supply curve for commodity 2 shifts downward from the base.

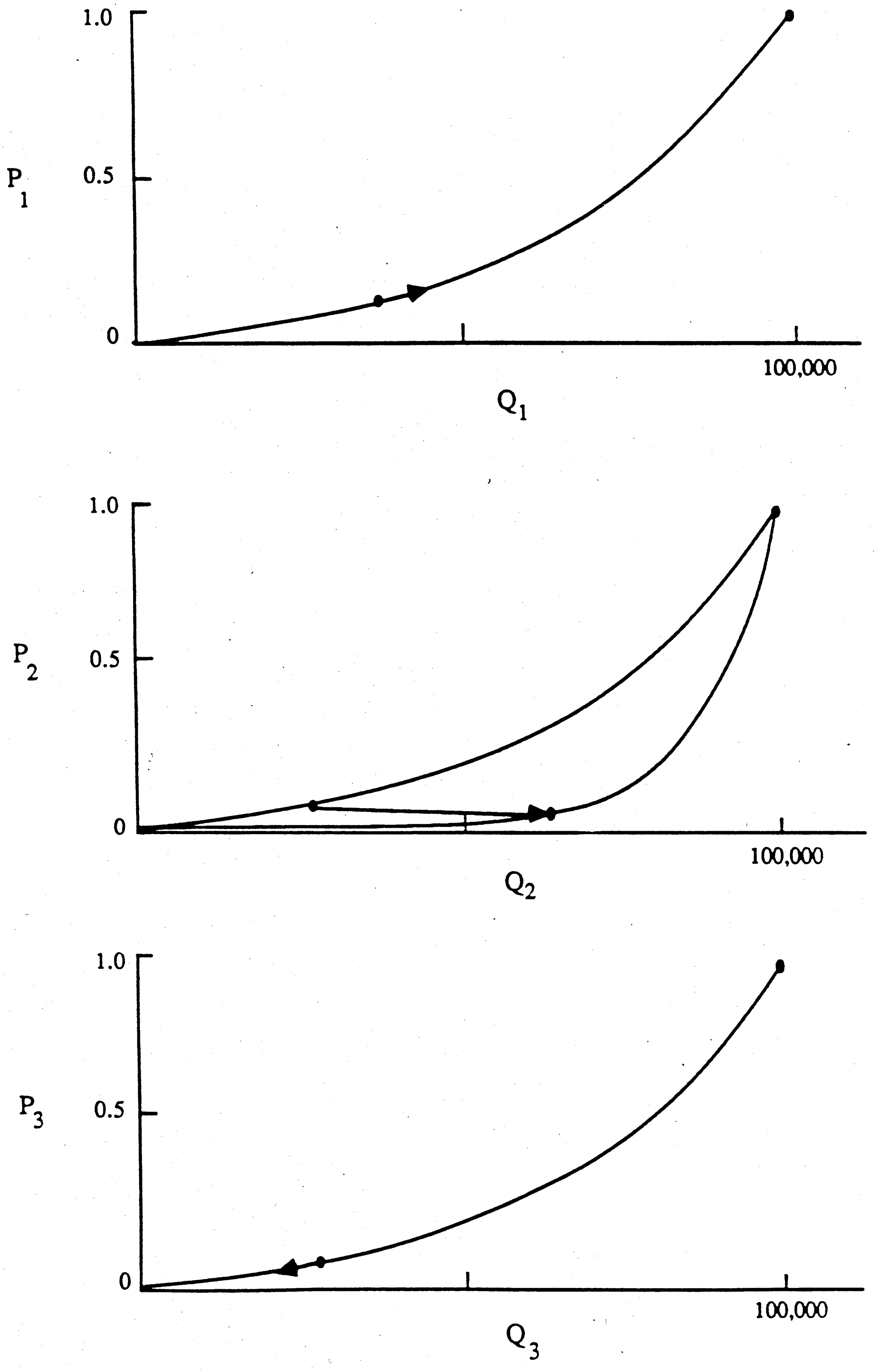

Figure 2. Adjustments as Described for Model A.