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A METHODOLOGY FOR MEASURING POTENTIAL BENEFITS FROM DROUGHT-ORIENTED RESEARCH IN NEBRASKA

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Introduction

The growth in agricultural productivity and the significance of science and technology in contributing to this growth has been well documented by Bredahl, Cline, Evenson (1967), Griliches (1964), and Peterson. The results of these studies generally indicate that over the past several decades, investment in agricultural research has paid off with relatively high rates of return. Most of this previous work, however, has been directed at estimating returns to aggregate agricultural research in an *ex post* sense at the national level and does not address the question of potential future returns to research at a state or regional level (Norton). Thus, a particular need exists to develop a methodology for evaluating the potential returns to specific types of agricultural research at a subnational level.

The allocation of agricultural research funds in the United States is determined in large part by political decisionmakers and research administrators at the state level. Although aggregated, national-level, *ex post* estimates of returns to research are useful to state-level research administrators as indicators of research potential and as a means of justifying funding requests, they are not directly applicable to the larger issues involved. A state-level assessment of the effects of agricultural research should be as situation specific as possible, considering at least the geographic distribution of benefits and the division of benefits between consumers and producers. Essentially, research administrators need to know which types of agricultural research can be expected to have the highest payoffs and to whom the gains will accrue.

Answers to questions regarding the magnitude and distribution of agricultural research benefits depend on five primary factors: (1) the impact which a research finding has on production possibilities, (2) the rate and extent of adoption, (3) supply elasticities of the commodities affected, (4) price elasticities of demand for the commodities affected, and (5) agricultural policy. An analysis of potential returns to agricultural research at the state level must consider each of these factors. The purpose of this paper is to present a general conceptual framework for such analyses and also to describe how this framework is being applied in a study of potential returns to research in Nebraska.

Conceptual Framework

The genesis of an agriculturally related technological development occurs in either the publicly supported agricultural research establishment or in the private sector. A technological development influences the production possibilities of agricultural commodities in two major ways: (1) an output-increasing effect or (2) a cost-reducing effect.

An example of an output-increasing technology is an improved crop variety; a cost-reducing technology may involve a change in cultural practices, such as minimum tillage. Generally, a change in technology which results in the same output per acre from fewer inputs is said to be cost-reducing. Similarly, a change in technology which shifts an isoquant to a higher output level with the same level of inputs is considered output-increasing. In reality, most technological changes embody both output-increasing and cost-reducing effects. Finally, both types of technological advances will influence the cost of production and therefore the production possibilities of the agricultural commodities influenced by the technological development.

Once a new technology has been developed, at what rate, to what extent and by whom will it be adopted? How will producers react, assuming an objective of profit maximization? New knowledge generated by private or public research must be

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disseminated and adopted by farmers before it can influence agricultural production. The rate of diffusion of a new technology depends to a large extent on profitability, degree of uncertainty and capital requirements (Lu). Profitability is the most important determinant of the rate of diffusion. Griliches, in his seminal work, indicated that hybrid corn was adopted more rapidly in areas where it was most profitable (Griliches, 1958). In general, it appears that the most rapidly and most extensively adopted innovations are those which are highly profitable, have a relatively certain impact, and require relatively small capital expenditures.

Assuming that a new technological development is profitable for farmers to undertake, how will farmers adjust their crop production patterns? The new technology will lower the cost of production. This will stimulate the early adopter of the new technology to adjust his farming practices. In the early stages of adoption of the new technology, the early adopter will capture some excess profits because his increased production will not have a major effect on commodity prices. Eventually, other producers may adopt the new technology which will cause declines in commodity price, ceteris paribus. The magnitude of these commodity prices declines will depend in part on whether the new technology is global or site specific in nature. Thus, understanding diffusion of technology is crucial to determining its impact at the farm, state or national level (Heady).

If a state's production of a particular agricultural product is small compared to the national or world output, state-specific agricultural research may lower production costs and/or increase state output relative to national output, and only slightly lower the output price (Huffman). The implication here is that a state's farmers should demand state-specific final research products that improve their comparative advantage relative to farmers in other areas. The benefits accrue to them largely as producer's surplus and to the owners of inputs that are very inelastic in supply such as land or water, other things equal (Evenson 1979).

At the national or international level, consumers are the primary beneficiaries of agricultural research, providing agricultural policy doesn't limit price declines resulting from technological change. The price elasticity of demand in the policy-independent case is so low at the national level that the long-term primary impact of agricultural research is to lower the price of agricultural products and to benefit consumers.

Consideration of the factors which influence returns to research makes it evident that an analytical framework for assessing potential returns must consider both returns to producers (producer surplus) and return to consumers (consumer surplus). It follows, that, in order to estimate these factors, one must know the before and after supply function for all affected commodities and also the prevailing demand relationships. Supply function estimates essentially incorporate all of the production response aspects of technological change, while demand functions are necessary to assess the resulting price responses and corresponding distribution of benefits between producer and consumer.

Estimates of potential returns to specific state-level research programs require that one consider which commodity supply functions will be affected both within and outside the state and how these effects interact with prevailing commodity demands to produce a given magnitude and distribution of research benefits. A hypothetical case example is presented below for purposes of illustrating these interactions and also as a means of demonstrating the relevance of selected key parameters. This case example can also be viewed as a generalized model for assessing potential returns to state level agricultural research.

A Generalized Case

Assume for simplicity that the relevant portion of the United States agricultural economy can be described as consisting of two producing regions, a given state and "other U.S.", each with two enterprise options, X and Y. Further assume that regional supply and total United States demand functions have been defined for each commodity and can be written as:

$$QS^o_{xs} = 400P_x - 800$$
$$QS^o_{xo} = 4000P_x - 8000$$
$$QD_{xt} = 13{,}200 - 1650P_x$$
$$QS^o_{ys} = 125P_y - 500$$
$$QS^o_{yo} = 2500P_y - 10{,}000$$
$$QD_{yt} = 15{,}000 - 1000P_y$$

where:

QS^o_{xs} = quantity of X supplied in region S (state), before technological change,

P_x = price of X,

QS^o_{xo} = quantity of X supplied in region O (other U.S.) before technological change,

QD_{xt} = quantity of X demanded, total U.S.,

QS^o_{ys} = quantity of Y supplied in region S before technological change,

P_y = price of Y,

QS^o_{yo} = quality supplied of Y in region 0 before technological change,

QD_{yt} = quantity demanded of Y, total U.S.

These equations provide a basis for computing initial (before technological change) producer and consumer surpluses.

Producer surpluses for the two regions can be computed by horizontally summing the regional supply functions to determine aggregate supply for each commodity, setting it equal to quantity demanded to determine an equilibrium and then computing producer surplus as the area above the supply curve at the equilibrium price. For our illustration, aggregate supply for the two commodities is:

$$QS^o_{xt} = QS^o_{xs} + QS^o_{xo} = 4400P_x - 8800 \text{ and}$$

$$QS^o_{yt} = QS^o_{ys} + QS^o_{yo} = 2625\ P_y - 10{,}500$$

Setting $QD_t = QS^o_t$ to determine an initial equilibrium price for each commodity yields P_x = \$3.64 and P_y = \$7.03. At these prices, QS^o_{xs} = 656 and QS^o_{ys} = 379. Thus, initial producer surplus for region S is \$1,112 per production period, consisting of \$538 for commodity X and \$574 for commodity Y. The corresponding producer surplus for region 0 is \$16,855, consisting of \$5,379 for X and \$11,476 for Y (Table 1).

Initial consumer surplus consists of the area under the demand at the equilibrium prices and is thus \$47,428 with \$15,731 from commodity X and \$31,697 from commodity Y.

The next and most difficult step in an analysis of potential returns to research consists of determining what impact a research program might have on farm level production possibilities, how farmers will respond to this change, and thus how the commodity supply function will shift. Different types of research will, of course, have quite different impacts.

For purposes of illustration, assume a commodity-specific technological change which applies only to commodity X. Assume further that the change shifts the supply function to the right by a substantial amount in region X (state) and by a lesser amount in region 0 (other U.S.).

This illustrative supply shift could be brought about by either a reduction in per-unit cost with no change in output per unit of land (cost-reducing) or through a corresponding equivalent increase in yield per acre (output-increasing). Thus, a modified supply function for X in regions S and 0 can be depicted as follows:

$$QS'_{xs} = 400P_x - 600$$

$$QS'_{xo} = 4000P_x - 7000$$

Where:

QS'_{xs} = quantity of X supplied in region S after technological change, and

QS'_{xo} = quantity of X supplied in region 0 after technological change.

Note that for both regions the supply functions have been shifted parallel and to the right depicting a constant per-unit change in cost at each output level. The assumed cost decrease per unit of production was assumed to be \$.50 in region S and \$.25 in region 0. This reflects limited transferability of the assumed state level research.

Although a given technological change may be directly applicable to only a single commodity, supply functions for other enterprise options may also change. An increase in the production of product X brought about by a technological change may increase or decrease the production of alternative enterprises depending on how production possibilities and relative prices are affected. This is an extremely important effect to consider, because it may be this phenomenon which accounts for much of the net change in producer surplus.

This "induced impact" of commodity-specific research occurs in agriculture because of the significance of land as the limiting input. Agricultural producers are essentially landholders who allocate limited land to alternative enterprises and for this reason one cannot limit a producer surplus assessment to only one commodity. If the relevant set of producers is involved in producing commodities other than the one directly affected by a technological change, then the indirect effects of the technological change on these other commodities must also be considered as part of total producer surplus. In agriculture, one can handle these interdependent effects by considering acreage and yield shifts across all relevant commodities.

In effect, the aggregate linear programming (L.P.) algorithm, so often used in economic analysis, operates in a similar fashion as the above assumptions. A change in the production function of a given enterprise will influence that enterprise directly as well as the other enterprise activities in the L.P. model.

Assume for purposes of illustration that one knows the new supply functions for the directly affected enterprise (product X in our example) and that one also knows what effect the change has had on per-acre yields. By further assuming

Table 1. Producer and Consumer Surplus Estimates For a Generalized Case Example

Affected Parties	Before Technology Change	After Output-Increasing Technology Change	Difference	Percentage Change	After Cost-Reducing Technology Change	Difference	Percentage Change
	---Dollars Per Production Period---						
Producer's Surplus							
Region S							
Product X	538	753	+215	+39.96	753	+215	+39.96
Product Y	574	693	+119	+20.73	410	-164	-28.57
Total	1,112	1,446	+334	+30.04	1,163	+51	+4.59
Region O							
Product X	5,379	5,712	+333	+6.19	5,712	+333	+6.19
Product Y	11,476	11,795	+319	+2.78	11,183	-293	- 2.55
Total	16,855	17,507	+652	+3.87	16,895	+40	+0.24
Total All Producers	17,967	18,953	+986	+5.49	18,058	+91	+0.51
Consumers							
Product X	15,731	17,182	+1,451	+9.22	17,182	+1,451	+9.22
Product Y	31,697	32,805	+1,108	+3.50	30,420	-1,277	- 4.03
Total	47,428	49,987	+2,559	+5.40	47,602	+174	+.37
Total Producer and Consumer Surplus	65,395	68,940	+3,545	+5.42	65,660	+265	+0.41

that all available land is utilized for the production of either X or Y, one can then compute what the new supply function for Y would have to be in each region in order to maintain constant total acreage. This means that the after change supply functions for Y in each region will depend on how much of the given shift in supply of X occurs because of lower input costs (cost-reducing) and how much occurs because of increased production per unit of land (output-increasing). In order to assess the significance of output-increasing versus cost-reducing technological change, the following illustration considers the two extreme cases, i.e., where the entire shift in the supply of X is due to cost-reducing and output-increasing technology, respectively. For the case where the supply shift for X was assumed to be the result of an output-increasing technology, the following supply functions for commodity Y were computed for regions S and O:

$$QS'_{ys} = 125P_y - 446.5$$

$$QS'_{yo} = 2500P_y - 9,566$$

These supply functions assume that the output-increasing technological change caused the average yield of X per unit of land to change from 10 to 13.33 in region S and from 10 to 10.53 in region O. They further assume that the average yields of Y per unit of land were 5 and 6 for regions S and O, respectively, both before and after the technological change which affected product X (see Appendix for computational detail).

For the case where an equivalent supply shift for X was assumed to be the result of a cost-reducing technology, the yields per unit of land were held constant for both commodities. In this instance, the new regional supply function for product Y becomes:

$$QS'_{ys} = 125P_y - 580$$

$$QS'_{yo} = 2500P_y - 10,520$$

At this point, the information base is complete for estimating the change in producer and consumer surpluses associated with both a cost-reducing or output-increasing technological change. Given the above supply functions, the new equilibrium prices are P_x = \$3.44 for both types of technological changes, P_y = \$6.90 for the output-increasing case, and P_y = \$7.20 for the cost-reducing case. At these price levels, the new total producer surplus is \$18,953 for the output-increasing case, consisting of \$1,446 in region S and \$17,507 in region O. This means that the technological change induced a 30.04% increase in producer surplus for region S and 3.87% increase for region O. In contrast, the cost-reducing case caused only a 4.59% increase in producer surplus for region S and a 0.24% increase for region O (Table 1).

Table 1 illustrates a particularly interesting finding. Both consumers and producers in all regions gain substantially more from the output-increasing technological change than they do from the "equivalent" cost-reducing change. Although the cost-reducing and output-increasing effects are clearly the same when only commodity X is considered, they are considerably different when the impact on enterprise Y is also included. This phenomenon occurs because the output-increasing technology causes a shift of the limited land resource to the production of commodity Y.

A Proposed Application of the Above Framework

The theoretical discussion outlined above serves as the framework for development of empirical estimates of the influence new technologies may have on Nebraska farm incomes (producer surplus). The initial step in the empirical framework involves an estimate of the potential input/output changes resulting from a new technology.

A number of approaches could be used to measure input/output changes resulting from a change in technology. Expert judgment of physical scientists could be employed to measure this component. Another approach could involve a historical review of the influence of past technological developments and draw inferences from this toward potential new technologies. Still another approach may involve an econometric analysis of input/output changes over time for crop or livestock activities.

The procedure for estimating potential input/output changes in the proposed study will involve a combination of an econometric approach and expert professional judgment. The case example is for development of a drought-tolerant technology for Nebraska's principal crops.

Farmer Response to a Change in Technology

Once an estimate has been made of a new technology's effect on input/output relationships, then the next step in the empirical estimating procedure is to measure farmer response to the new technology. What factors influence the likely response from Nebraska farmers resulting from development of a drought-tolerant technology? Several key factors include the relative profitability of the farm enterprises affected by the new technology, the degree of uncertainty associated with its adoption, and the capital requirements that are required for its adoption.

An aggregate linear programming model of each of the five study regions in Nebraska will be developed to determine farmers' supply response to the new technologies. This model will have an objective function of maximizing returns to land and management subject to the physical, agronomic, and managerial constraints relevant to each region. The principal crop activities in Nebraska (corn, grain sorghum, soybeans, wheat, and alfalfa) will be included in the model at four levels: a fully irrigated level, two partial irrigation levels, and a dryland level.

The adoption of a new technology may be sensitive to the varying costs of production reflected in the four crop irrigation levels as well as the physical, agronomic, and managerial constraints imposed on the model. The new technology itself may have differential cost of production effects on each of the four crop irrigation levels within the same crop, as well as among competing crop enterprises.

The purpose of the L.P. model, then, is to provide state supply functions for each crop activity, to generate estimates of the relative profitability of the new technology, and to illustrate the associated crop pattern shifts. However, the speed at which the technology will be adapted and the degree of spillover to other states are crucial parameters which must also be estimated in an empirical analysis and will influence the effect of the new technology on farm incomes.

The Price Response

The supply-price response that occurs as a result of the new technology will be a function of the "spillover" of the technology to other areas, the speed of adoption, and the price elasticity of demand for the commodity. The assessment of the spillover effects from any assumed technology change will involve the professional judgment of physical scientists and a review of the historical effects from similar innovations.

Once an assessment has been made of the spillover effects, the respective commodity price responses can be estimated. The study will use USDA's long-term National-International Agricultural Forecasting Model (NIRAP) to determine the price effects resulting from the implementation of the new technology.

The NIRAP model will provide a most likely scenario of commodity prices over time. The state supply response plus the spillover response from other regions will be summed. Then a supply shifter will be imposed on the "most likely" NIRAP scenario to account for the technology's supply-price response.

In effect, the statewide five-region aggregate L.P. will provide the Nebraska supply function estimates before and after a new technology has been implemented; while NIRAP will provide an estimate of the demand and the aggregate supply function adjustments associated with each crop (Quance). The sensitivity of commodity price changes associated with the new technology can be determined from the shadow prices of the L.P. model. An analysis with and without the new technology will provide the farm income effects (producer surplus) resulting from development and adoption of the new technology.

The adoption rate of the drought-tolerant technology will have an influence on farm income. In the early stages of adoption, the early adopter may capture some excess profits because the initial production increases will have a minimal impact on commodity prices or on any aggregate changes in cropping patterns. The technology's adoption rate will be incorporated into the linear program algorithm through a series of iterations to capture the commodity price and cropping pattern adjustments that are likely to occur through time. Adoptive rates will be posited based on profitability, uncertainty, and capital requirements. Additionally, the stream of benefits over time resulting from the drought-tolerant technology will be discounted to a single present value.

Summary

This paper has sought to develop a methodological framework for analyzing _ex ante_ farm income effects of potential new technologies at a subnational level. The framework will be applied to a case example for development of a drought-tolerant technology for Nebraska's principal crop commodities. While the drought-tolerant technology provides a case example, the methodological framework could be applied to a broader range of technological developments. The drought-tolerant technology was chosen as a case example because of available time series data that aided in estimating potential input/output changes in Nebraska's crop commodities and because the spillover effects to other regions which are difficult to estimate were thought to be minimal.

The _ex ante_ methodology outlined in this paper has some limitations. Estimates of farmer response and commodity price changes resulting from a new technology have large elements of subjective judgment inherent in them. While this may limit the accuracy of our analysis, the "what if" approach followed in this study in analyzing the farm income effects of potential new technologies should prove useful to research administrators in determining the payoff of new technologies and to whom those gains will accrue.

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Appendix

Computation of Supply Function Changes

The supply function adjustments for commodity Y assume a parallel shift and thus an intercept change. This change was computed by solving the following three equations simultaneously:

$$\frac{125P_y - I'_{ys}}{Y_{ys}} + \frac{QS'_{xs}}{Y'_{xs}} = A_{ts} \qquad \text{Equation 1}$$

$$\frac{2500P_y - I'_{yo}}{Y_{yo}} + \frac{QS'_{xo}}{Y'_{xo}} = A_{tu} \qquad \text{Equation 2}$$

$$3625P_y - I'_{ys} - I'_{yo} = 15{,}000 \qquad \text{Equation 3}$$

Where: Y_{ys} = yield per acre of y in region S, assumed to be 5 units.

Y_{yo} = yield per acre of y in region o, assumed to be 6 units.

Y'_{xs} = yield per acre of x in region S after technological change; assumed to be the initial 10 units for the cost reducing case and computed at 13.33 units for the output increasing case (the amount which is equivalent to the assumed 50¢ per unit cost reduction).

Y'_{xo} = yield per acre of X in region O after technological change; assumed to be the initial 10 units for the cost reducing case and computed at 10.53 units for the output increasing case and the amount which is equivalent to the assumed 25¢ per unit cost reduction.

A_{ts} = total acres in region S, computed at 141 acres based on the assumed yield and the initial equilibrium production levels.

A_{to} = total acres in region O, computed at 1,923 acres based on the assumed yields and the initial equilibrium production levels.

QS'_{xs} = equilibrium quantity of X supplied by region S after the technological change, computed at 776 units (see text).

QS'_{xo} = equilibrium quantity of X supplied by region O after the technological change, computed at 6,760 units (see text).

P_y = price of Y.

I'_{ys} = intercept term of supply function for Y in region S after technological change.

I'_{yo} = intercept term of supply function for Y in region O after technological change.

The above three equations, when solved simultaneously, insure that the total land base for both the regions is accounted for (Equations 1 and 2) and that the quantity demanded of Y is equal to quantity supplied (Equation 3).

When solved for the cost reducing case, one establishes: $I'_{ys} = 580$, $I'_{yo} = 10{,}520$ and $P_y = \$7.20$. For the output increasing case the solution is $I'_{ys} = 446.5$, $I'_{yo} = 9{,}566$ and $P_y = \$6.90$.