ID

A.E. RES. SER. #91-9

University of Idaho



## Department of Agricultural Economics and Rural Sociology

College of Agriculture
University of Idaho
Moscow, Idaho 83843

# THE ECONOMIC IMPACT OF TECHNOLOGICAL CHANGE ON U.S. AGRICULTURE

by

A. A. Araji and F. C. White

A.E. Research Series, No. 91-9

July 1991

# THE ECONOMIC IMPACT OF TECHNOLOGICAL CHANGE ON U.S. AGRICULTURE

By

Araji, A.A. and F.C. White

## Abstract

Several quantitative methods have been developed to evaluate the impacts of technological change on U.S. agriculture. The major weakness of prevailing models is that they consider the impact of technology on supply alone and are based on partial equilibrium analysis in one market. The use of partial equilibrium analysis ignores cross-market effect. For most goods, a supply shift directly affects quantity demanded by reducing the price of the commodity along a given demand curve. The resulting change in the equilibrium price may affect demand for substitute and complimentary goods, which in turn affect demand for the commodity being considered.

The primary objective of this paper is to analyze price effects and substitution effects of technological change in interrelated markets. An econometric model was developed and applied to the beef and pork industries to measure the social impacts of technological change. The multimarket supply-demand model developed in this paper includes technology variables in the specification of supply functions and the model explicitly accounts for the fact that technological change in one market influences demand for related products

This paper evaluates the welfare impact of technological change through the consumer-producer surplus model that incorporates the interaction of demand relationships for beef and pork. The results indicate that total returns for technological change in beef and pork are high. Technological change in beef affects economic surpluses in the pork market and technological change in pork affects economic

surpluses in the beef market. The actual allocation of expenditures for technological development over the study period (1960-1988) was 70% for beef and 30% for pork. However, the optimal allocation would have been a 40-60 split between beef and pork.

# THE ECONOMIC IMPACT OF TECHNOLOGICAL CHANGE ON U.S. AGRICULTURE

Griliches pioneered the measurement of the impacts of agricultural research. Several quantitative methods have been developed to evaluate the impacts of agricultural research since then. Two common approaches in ex-post research evaluation are the index number approach, which is associated with consumers' and producers' surpluses, and the production function approach (Ruttan). Methods developed to evaluate the economic impact of public investments in agricultural research have several weaknesses which lead to biases in the estimated returns (Fox; Pasour and Johnson).

A major weakness of prevailing models under the index number approach is that they are based on partial equilibrium analysis in one market, which ignores many of the major forces and interrelationships at work (Bieri, de Janvry, and Schmitz). Many authors assumed that the demand for the commodity being affected by the adoption of new technology is constant, and the evaluations considered only the supply shifting impact of technology. However, for most goods a supply shift directly affects quantity demanded by reducing the price of the commodity along a given demand curve. The resulting change in the equilibrium price may affect demands for substitute and complementary goods, which in turn affect demand for the commodity being considered. An income effect is also possible from advancing technology. Therefore, impacts of technological change on demand should also consider an evaluation of the welfare effects. Furthermore, analyses of impacts of technological change on social welfare should consider the effect on other related commodity and factor markets.

The production function approach is subject to the same criticism in that interrelated demand effects are not taken into account. With the duality between the production and supply functions, the production function approach is not really distinct from the index number approach, but it can be regarded as a limiting case of the index number approach that ignores the simultaneity that usually affects endogenous variables such as price and quantity of output. The marginal productivity of research expenditures estimated with the production function approach assumes constant prices, which accurately represents the true effects only if demand is perfectly price elastic. Demand relationships for most agricultural commodities are price inelastic (George and King), indicating that a shift in the supply curve from technological change will result in a lower price. Hence, production function approach overestimates the marginal productivity of research expenditures by assuming output price remains constant. Weaknesses of prevailing models using the index number and production function approaches lead to an overstatement in the estimated returns.

The primary objective of this paper is to analyze the impacts of technological change in interrelated markets. First, the multimarket supply-demand model developed in this paper includes technology variables in the specification of supply functions. Second, this model explicitly accounts for the fact that technological change in one market influences demand for related products. Third, this model simultaneously analyzes the welfare impacts of related markets. The multimarket model developed in this paper is applied to the beef and pork industries to measure the social impacts of technological change. Simulation with the estimated empirical model is used to analyze allocation of research expenditures.

## The Multimarket Equilibrium Model

Consider a system of equations representing competitive multimarkets for agricultural commodities. The general case for demand and supply equations would be:

(1) $Q_i = D_i(P_1, \ldots, P_n, Z_i) \quad i = 1, \ldots, n$

(2) $Q_i = S_i(P_1, \ldots, P_n, W_1, \ldots, W_m, T_i) \quad i = 1, \ldots, n;$

where equation (1) is the demand for the ith commodity with quantity Q a function of prices P and exogenous variables Z; and equation (2) is the supply of the ith commodity with quantity a function of prices P, input prices W, and exogenous variables including technology T.

These relationships will be used to analyze the impact of a technological change within the context of multimarkets. A technological change in the production of one commodity is assumed to shift the supply curve for that commodity and impact the supply and demand curves for other commodities. For simplicity, assume only two commodities and an interrelationship between demands for the two commodities and not supplies. This case is illustrated in Figure 1. With a technological change the supply for commodity 1 is increased from $S_1$ to $S_1'$, resulting in a reduction in price from $P_1$ to $P_1'$. However, the lower price for commodity 1 will reduce demand for commodity 2, which is assumed to be a substitute. The reduced demand for commodity 2 will reduce its price and eventually reduce the demand for commodity 1. The resulting further reduction in the price for commodity 1 causes demand for commodity 2 to shift back even further. So the dynamic process continues until eventually, in the limit, the final demands appear similar to those shown in Figure 1. In particular, the demand for commodity 1 is assumed to shift from $D_1$ to $D_1'$ and the demand for commodity 2 is assumed to shift from $D_2$ to $D_2'$. An important conclusion from this discussion is that when one commodity gets cheaper the demand for it and all substitutes shift back.

The new demand curves $D_1'$ and $D_2'$ are used in conjunction with the appropriate supply curves to identify the new equilibrium prices and quantities and economic surpluses. Since demand is utility screened through income and prices, when the price of one commodity falls, its opportunity cost falls, and willingness to pay for it and all substitutes fall. In market 1 consumer surplus after the technological change would have been $acP_1'$ without any interrelationships between the two markets. Taking these interrelationships into account yields a consumer surplus of $bdP_1''$ after technological change. Likewise, consumer surplus in market 2 would be $fhP_2$ without interrelationships among markets compared to $giP_2'$ after accounting for these interrelationships. With technological change and interrelationships among markets the producer surplus would be $edP_1''$ in market 1 and $jiP_2'$ in market 2. If these interrelationships are important then failure to account for them would bias estimated economic surpluses.

## Empirical Model and Estimation

The model is composed of four behavioral equations for the supply and demand for beef and pork. Quantities and prices of beef and pork are the four endogenous variables.

(3) Beef Demand: $Q_{Beef} = f_1(P_{Beef}, P_{Pork}, Y)$

(4) Beef Supply: $Q_{Beef} = f_2(L(P_{Beef}), M_{Beef}, L(R), P_{Corn})$

(5) Pork Demand: $Q_{Pork} = f_3(P_{Beef}, P_{Pork}, Y)$

(6) Pork Supply: $Q_{Pork} = f_4(P_{Pork}, M_{Pork}, L(R), P_{Corn})$

where

P is a price index (using a Divisia index approach),

Q is quantity index obtained by dividing revenue by Divisia price index,

Y is per capita income,

M is marketing margin, and

R is research expenditures, and

L is the lag operator used to reflect a 3-year moving average for beef prices in the supply equation and a 5-year moving average for research expenditures.

Beef and pork are measured in reference to the broiler price which is used as the numeraire price. In order to account for the longer biological lags in the beef sector, the supply price for beef is a 3-year moving average.

Demand equations include own-price and cross-price variables and an income variable. Prices are at the retail-level. Hence, the supply equations include a marketing margin variable as well as the retail price variable to measure the farm-level price. In addition, supply equations include a research expenditures variable and corn price as a cost of production variable. The research expenditure variable is a 5-year moving average to reflect lags in the development and adoption of new technologies.

The model is formulated as being linear in logarithms. With this formulation the coefficients are elasticities. The model is estimated using three stage least squares in order to correct for correlation of errors across models.

Measurement of consumer surpluses in a log-log model such as the one used in this study is somewhat more difficult than it appears on the surface, because a log-log demand curve does not intersect the vertical axis. A maximum price of 5 times the base price is imposed in order to calculate consumer surplus.

## Data

The U.S. beef and pork sectors were analyzed using annual time series data for the 1960-1985 period. Data sources for prices and quantities are from Agricultural Statistics (USDA). Fed and non-fed beef prices were aggregated into a single price index using Divisia price indexes (Diewert). For consistency, other prices were also converted to indexes with 1979 as the base period. Quantity indexes of beef and pork were computed by dividing beef and pork revenue by the respective price indexes. All prices are normalized with respect to the price of broilers. Per capita income and the Consumer Price Index were obtained from the Statistical Abstract of the United States (U.S. Department of Commerce). Income estimates were deflated by the Consumer Price Index. Research expenditures for the 1967-1985 period were obtained from the Inventory of Agricultural Research (USDA) with earlier years obtained through extrapolation from regression analysis.

## Empirical Results

### Econometric Analysis

The estimated parameters for the supply and demand models for beef and pork are presented in Table 1. The overall fit of the model was good as indicated by the system weighted R-square of 0.93. Nineteen out of twenty coefficients had the anticipated signs. The one unexpected but insignificant coefficient, which was on the corn price in the beef supply equation, would not interfere with later simulations. A large number of signs consistent with economic theory is very important for later simulations.

All price elasticities were inelastic as expected. Following a suggestion by King, the elasticity estimates will be compared with previous estimates. From the demand equations, the own-price elasticities for beef and pork were -0.18 and -0.69, respectively. Freebairn and Rausser reported these elasticities to be -0.39 and -0.84, respectively. Arzac and Wilkinson reported the elasticity for pork to be -0.87 but did not report a similar elasticity for aggregate beef, estimating instead fed and non-fed beef separately. Hence, the own-price elasticities in this study are not significantly different from these previous estimates. The cross-price elasticities in the demand equations for beef and pork were positive, indicating the two products are substitutes. These substitution effects have important implications for later simulations, because a change in one market will affect the other market. The cross-price elasticities and income elasticities are not significantly different from previous estimates by Freebairn and Rausser and Arzac and Wilkinson.

Simulation Analysis

The supply-demand relationships for beef and pork shown conceptually in equations (3) through (6) and more explicitly in Table 1 were used as a basis to simulate selected changes in research expenditures. The parameters used in this analysis are from Table 1 and all exogenous variables other than research expenditures were set at their mean value during this study period 1960-1985. Equilibrium values for the endogenous variables of beef price, beef quantity, pork price, and pork quantity were solved simultaneously for given values of research expenditures and mean values of the exogenous variables.

Two types of simulation were conducted with this model. First, the impacts of independent adjustments in beef and pork research expenditures were analyzed. Secondly, the simultaneous adjustment of beef and pork research expenditures were analyzed to determine the optimal allocation of research expenditures.

Consider the case where all exogenous variables are held constant at their mean values for the study period. The equilibrium conditions for quantities and prices for these mean values form the base solution. Then beef research expenditures are assumed to be increased 10% on a sustained basis, while all other exogenous variables are held constant at their mean values. The impact of this change in beef research expenditures is shown in the first data column of Table 2. The new equilibrium quantity of beef would be 1.49% higher than the base equilibrium and the new equilibrium quantity of pork would be 0.75% lower than the base equilibrium. Each dollar of additional beef research expenditures would increase consumer surplus in the beef market by $78.43 and increase consumer surplus in the pork market by $47.42. For consumers the cross-market effects of beef research are 60% of the own-market effects. For producers the cross-market effects of beef research are greater than own-market effects. Hence, the cross-market effects of beef research appear to be very important.

A sustained 10% increase in pork research expenditures would reduce the equilibrium quantity of beef 1.80% relative to the base equilibrium and increase the equilibrium quantity of pork 7.15% (Table 2). Each additional dollar of pork research expenditures would increase consumer surplus in the beef market by $58.62 and increase consumer surplus in the pork market by $401.05. For consumers the cross-market effects of pork research are 15% of the own-market effects. For producers the cross-market effects of pork research are 37% of the own-market effects. Hence, these cross-market effects for pork research appear to be important but not as large as those for beef research.

Differences in cross-market effects of technological change can be attributed to the differences in elasticities of supply and demand and differences in the relative sizes of markets.[1] Specifically, the estimated price elasticity of demand is greater for pork than for beef so a given technological change would have a greater impact in terms of economic surplus in the pork market than in the beef market.

The optimal allocation of research expenditures was estimated by varying the proportions of research expenditures devoted to beef and pork. This approach was constrained so that the total research expenditures for both beef and pork would equal the mean expenditures for these two categories over the period of the study. Estimates of total economic surplus for the two markets for various allocations of research expenditures are shown in Figure 2. The actual proportion of expenditures allocated to beef is approximately 70%. Reducing the percentage of expenditures allocated to beef below 70% increases economic surplus over a range before it starts turning down. The maximum economic surplus is achieved by allocating 40% of the expenditures to beef and 60% to pork. However, the surplus function is relatively flat between 35% and 50%.

## Conclusions

A major problem associated with the previous studies on research evaluation has been that the effects on related markets resulting from technological changes were not considered. Consequently, by ignoring these cross-market effects, the estimated consumer and producer surpluses are biased if this cross-market effect is significant. The larger the substitution effects, the greater the overestimation of social benefits.

Social benefits resulting from technological changes in the beef and pork industries were estimated by using the multimarket equilibrium approach. Results indicate that total returns for research in beef and pork are high. However, beef research affects economic surpluses in the pork market and pork research affects economic surpluses in the beef market. For consumers the cross-market effects of research were 15%-60% as high as own-market effects. For producers the cross-market effects of research were 37%-128% as high as own-market effects. Hence, ignoring these cross-market effects in some markets might make little economic difference but in some cases these cross-market effects appear to be economically important. The size of the cross-market effects will depend on such factors as own- and cross-price elasticities and the nature and magnitude of the shift in the supply curve.

These cross-market effects of technological change have implications for the optimal allocation of research funding. The cross-market effects of research on economic surpluses caused the economically efficient level of beef research expenditures to be below the actual level of beef research expenditures. The actual allocation of research expenditures over the study period was 70% beef and 30% pork. However, the optimal allocation would have been almost a 40-60 split between beef and pork.

This study has examined the impact of technological changes in horizontally related markets. Although only substitute products were considered the framework is also applicable to complementary products. Furthermore, the methodology developed in this paper could be expanded to vertically related markets such as grains and livestock.

## References


Arzac, Enrique R. and Maurice Wilkinson. "A Quarterly Econometric Model of United States Livestock and Feed Grain Markets and Some of Its Policy Implications." Amer. J. Agr. Econ. 61(1979):297-308.

Bieri, Jorg, Alain de Janvry, and Andrew Schmitz. "Agricultural Technology and the Distribution of Welfare Gains." Amer. J Agr Econ. 54(1972):801-808.

Diewert, W. E. "Exact and Superlative Index Numbers." J. Econometrics 4(1976):115-145.

Fox, Glenn. "Is the United States Really Underinvesting in Agricultural Research?" Amer J. Agr Econ. 67(1986):806-812.

Freebairn, J. W. and G. C. Rausser. "Effect of Changes in the Level of U.S. Beef Imports." Amer J. Agr. Econ. 57(1975):676-688.

George, P. S. and G. A. King. "Consumer Demand for Food Commodities in U.S. with Projections for 1980." Giannini Foundation Monograph 26, 1971.

Griliches, Zvi. "Research Costs and Social Returns: Hybrid Corn and Related Innovations." J. Polit. Econ. 66(1958):419-431.

King, Richard A. "Choices and Consequences." Amer J Agr. Econ. 61(1979):839-840.

Pasour, E. C., Jr. and M. A. Johnson. "Bureaucratic Productivity: The Case of Agricultural Research Revisited." Public Choice 39(1982):301-317.

Ruttan, Vernon W. "Bureaucratic Productivity: The Case of Agricultural Research." Public Choice 35(1980):529-547.

Schmitz, Andrew and David Seckler. "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester." Amer. J. Agr. Econ. 52(1970):569-577.

U.S. Department of Agriculture. Agricultural Statistics. U.S. Government Printing Office, Washington, D.C., Various issues.

U.S. Department of Agriculture. Inventory of Agricultural Research. U.S. Government Printing Office, Washington, D.C., Various issues.

U.S. Department of Commerce, Bureau of the Census. Statistical Abstract of the United States. U.S. Government Printing Office, Washington, D.C., Various issues.

Footnote

[1]Although the system of supply and demand equations was estimated as a log-log model, linear supply and demand relationships would also have important cross-market effects. With linear relationships, the cross-market/own-market ratios for consumers were -.29 and -.42 for beef and pork research, respectively. Likewise, the cross-market/own-market effects for producers with linear relationships were 1.69 and 1.03 for beef and pork research, respectively.

Table 1. Estimated Demand and Supply Equations for Beef and Pork, United States, 1960-1985

| Variables | Quantity: Beef | Quantity: Pork |
|---|---|---|
| Demand | | |
| Intercept | -3.343<br>(-0.896)[a] | -5.266<br>(-0.707) |
| Beef Price | -0.184<br>(-0.566) | 0.248<br>(0.822) |
| Pork Price | 0.220<br>(0.822) | -0.694<br>(-0.811) |
| Income Per Capita | 1.624<br>(3.573) | 1.948<br>(2.133) |
| Supply | | |
| Intercept | 5.456<br>(1.470) | 2.322<br>(1.338) |
| Beef Price (3 yr. av.) | 0.507<br>(1.503) | |
| Pork Price | | 0.243<br>(0.718) |
| Marketing Margin | -0.955<br>(-3.531) | -0.371<br>(-1.598) |
| Research (5 yr. av.) | 0.742<br>(2.094) | 0.964<br>(5.625) |
| Corn Price | 0.255<br>(1.470) | -0.068<br>(-0.669) |
| System Weighted R-Square | 0.934 | |

[a]The numbers in parentheses are t-values.

Table 2. The Impacts of Changes in Research Expenditures for Beef and Pork

| | Sustained 10% Change in | |
|---|---|---|
| | Beef Research | Pork Research |
| Percentage Change in | | |
| Quantity of Beef | 1.49% | -1.80% |
| Quantity of Pork | -0.75% | 7.15% |
| Price of Beef | -7.55% | -3.51% |
| Price of Pork | -3.06% | -10.63% |
| Change in Economic Surplus Per Dollar Change of Research Expenditures | | |
| Consumer Surplus for Beef | \$78.43 | \$58.62 |
| Consumer Surplus for Pork | \$47.42 | \$401.05 |
| Cross-Market/Own-Market Ratio | 0.60 | 0.15 |
| Producer Surplus for Beef | -\$45.72 | -\$58.62 |
| Producer Surplus for Pork | -\$58.74 | -\$156.67 |
| Cross-Market/Own-Market Ratio | 1.28 | 0.37 |

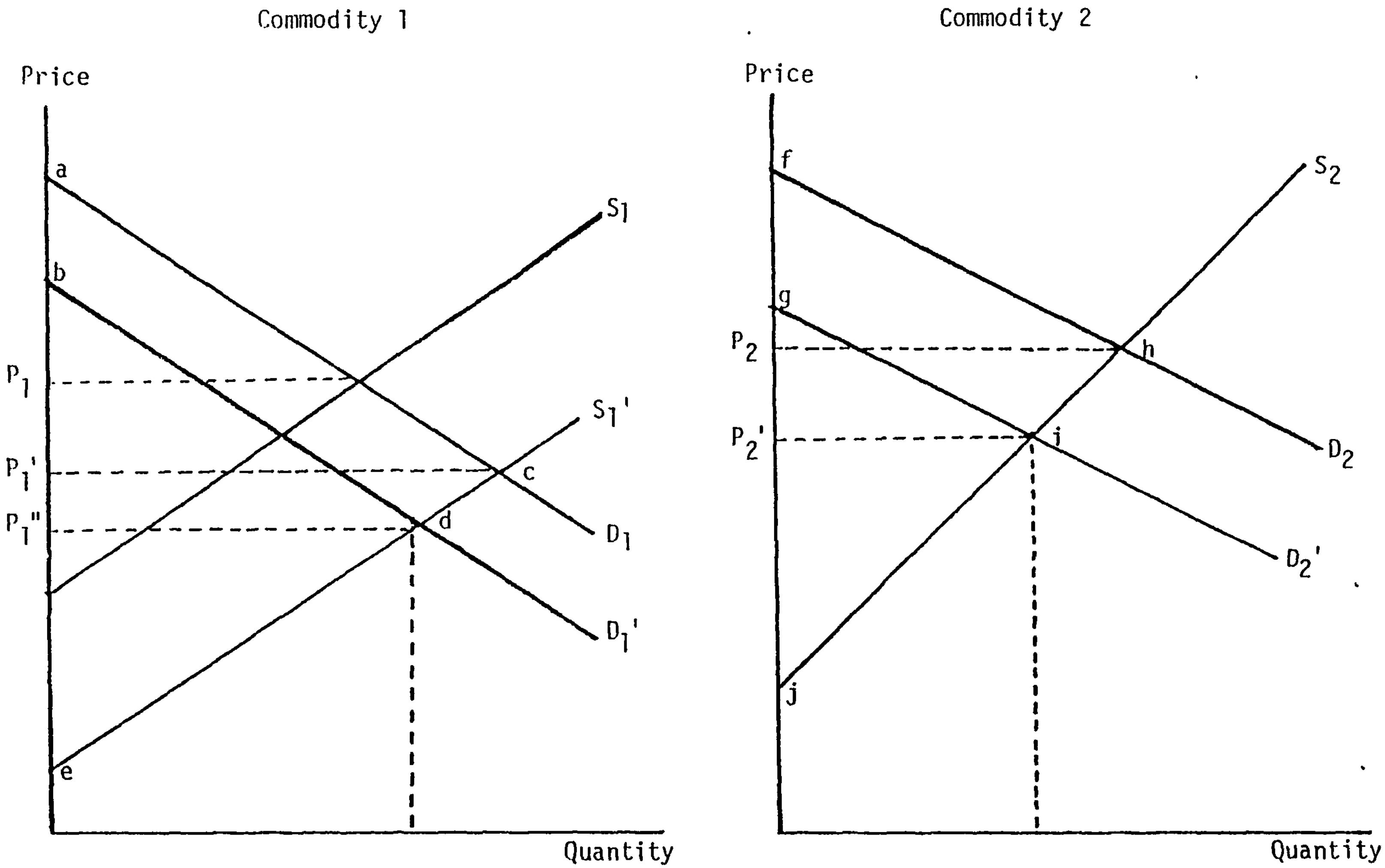


Figure 1. Supply and Demand Curves for Two Related Markets

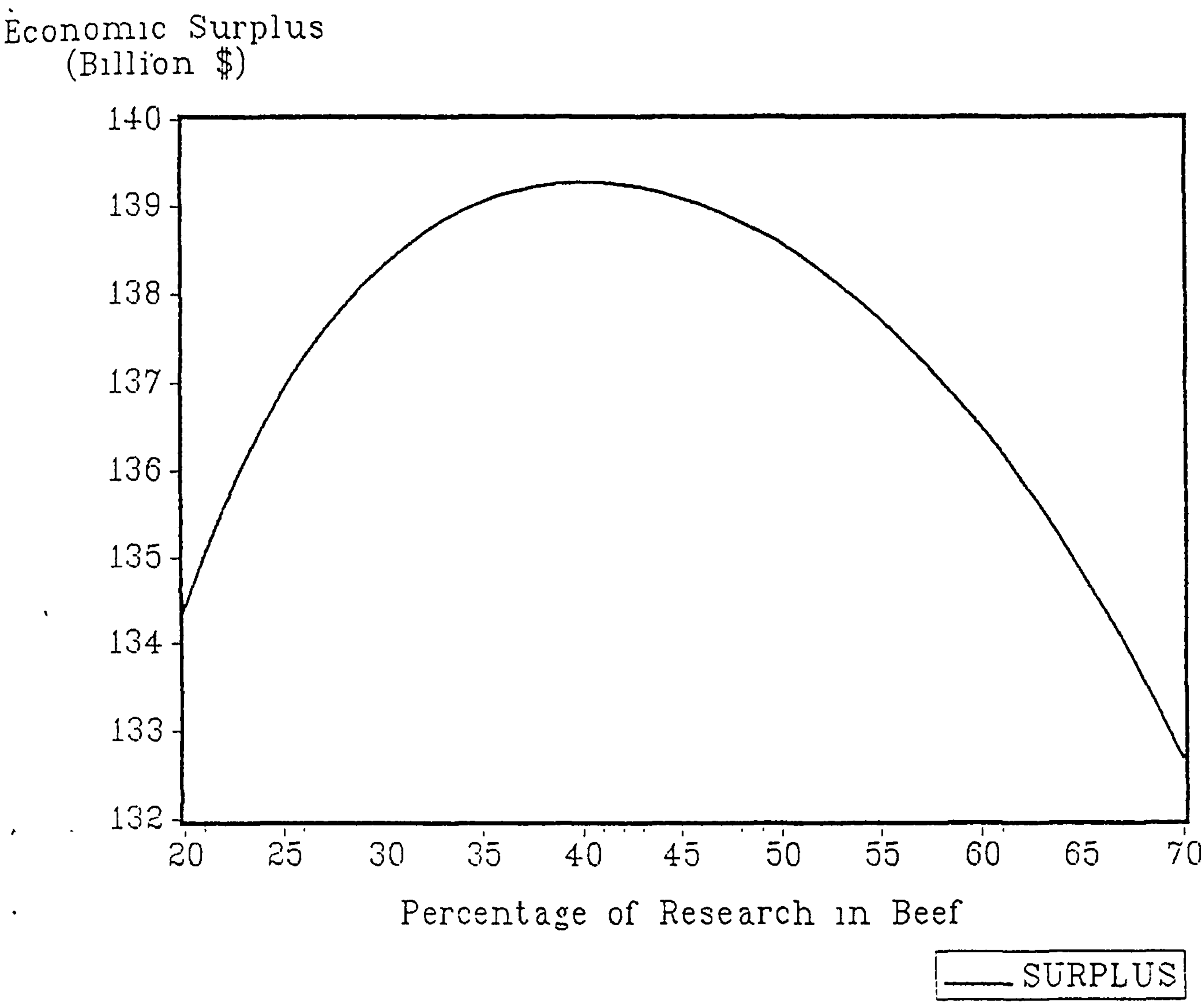


Figure 2. Relationship of Research Allocation and Economic Surplus