PART V

Public Programs

Chapter 13

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Technological Research in Relation to Adjustments

MY task is to discuss the problem of reallocating resources for technological research in agriculture. The assignment further divides this general problem into two subproblems: (1) On what basis is technological research in agriculture justified, and (2) in which agricultural innovations should society invest? Implicit in this statement of the problem are the assumptions that: (1) society should invest in some innovations, (2) technological research in agriculture is justified on some basis, and (3) we do not have an optimum allocation of resources for technological research in agriculture.

To begin a study of technological research in agriculture with these assumptions appears untenable, because these assumptions suggest that we already know the goals or ends of society, that we already know the consequences of technological research, and that these consequences are in some degree consistent with the attainment of these ends but could be made more consistent by a reallocation of resources. I am not convinced at the outset that we have all this knowledge. Unless the consequences of technological research can be predicted and unless the ends society upholds are clearly known, suggestions on how to allocate resources for this research in agriculture are less than satisfying as a basis for taking action.

Since goals and values related to agricultural adjustments are evaluated elsewhere in this conference, I shall address myself primarily to predicting the consequences of choices in resource allocation for technological research in agriculture. However, since my assignment calls for a discussion of the basis upon which technological research is justified, I shall deal briefly with this aspect first. To the extent that "bases" are synonomous with goals and values, a discussion of bases for technological research also relates concepts of what ought to be to technological research. Discussing bases for justifying technological research prior to predicting consequences of alternative resource allocations for such research separates normative preconceptions of what ought to be from propositions postulated for prediction. This separation reduces the risk of propositions postulated for prediction being rejected on the

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basis of normative preconceptions, even though these propositions yield predictions which experience later confirms. Thus, if certain propositions or models later postulated logically do predict particular techniques as having high output-increasing probabilities, the acceptance or rejection of these propositions should rest eventually on whether they indeed do predict as expected rather than on whether the consequence is considered desirable or undesirable.

POSSIBLE BASES FOR PUBLIC SUPPORT FOR TECHNOLOGICAL RESEARCH IN AGRICULTURE

State acts in Michigan (1857), Iowa (1858), and Minnesota (1859), and the Morrill Act of 1862 invited science to aid agriculture. Through succeeding acts, such as Hatch, Purnell, Research and Marketing, society has come to assume the major role for furthering technological research in agriculture and for extending the results. In 1951, federal and state expenditures for agricultural research alone totaled almost 109 million dollars.[1]

Early motives and needs for public support of technological research in agriculture might be discussed at this point. However, at this juncture tracing some of the major consequences of such research is more useful because, if for example, the consequences have failed to contribute to the attainment of society's goal, no rational basis exists on which to justify this research.

Economic progress can be defined as a change "which enables man to obtain a given quantity of ends with a smaller quantity of means or what is the same thing, to obtain a larger quantity of ends with a given quantity of means."[2] On the basis of this definition few would deny that technological research in agriculture has contributed in a major way to economic progress. Aggregate farm output in the 1952-56 period was 51 percent greater than in the 1925-29 period while population, the consumption base, was only 37 percent greater in 1952-56 than in 1925-29. This larger output was attained with only a slight increase in inputs. According to one source, in terms of 1946-48 input prices, only 14 percent more inputs were used in 1950 than in 1910, while output increased 75 percent during the same period.[3] Another source states that during the period from the close of World War I to 1948, total production inputs in agriculture, valued in constant dollars, increased about 15 percent, while volume of farm output increased by 50 percent.[4]

Technological change in agriculture has thus enabled us to attain a considerably larger quantity of ends with only a slight increase in means.

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[1]Central Project Office, Agricultural Research Administration, U. S. Department of Agriculture.

[2]Boulding, K., Economic Analysis, 1948, p. 647.

[3]Schultz, T. W., The Economic Organization of Agriculture, 1953, pp. 108-9.

[4]Barton, G. T., "Effects of technological changes on cost reduction in agriculture: recent and prospective changes," Jour. Farm Econ., Vol. 21, Proceedings Issue, p. 442.

This statement takes on significance when we point out that between 1910 and 1955 total farm employment decreased from 13.6 million to 8.2 million and that the persons supported per farm worker increased from 4.5 in 1860 to 20 in 1956. Moreover, these persons were supported at levels far above subsistence. Technological change in agriculture has permitted a large diversion of manpower into secondary and tertiary industries and in consequence our welfare potential has increased greatly. As food production has required relatively fewer and fewer of our total resources, more resources have become available for the production of nonsubsistence or luxury goods and services. Hence, as consumers, our opportunities for exploiting the utility from these nonsubsistence goods and services have increased. Whether our total welfare has increased because of these opportunities must be decided in the fields of philosophy, ethics, or religion.

Boulding has pointed out, "The goal must be the right ends" to which he adds "plus the power to achieve them."[5] Certainly the consequences of technological research in agriculture have increased our power to attain ends, i.e., they have increased our welfare potential.[6] If to increase our welfare potential is one of society's goals, then the power to attain greater quantities of nonsubsistence goods and services as a result of technological change in agriculture becomes an important basis for public support of technological research in agriculture. Moreover, this power to attain can be extended beyond greater quantities of nonsubsistence goods and services for ourselves. A consequence of technological research in agriculture is the ability to produce food and fiber over and above our own needs. This surplus can be used to alleviate hunger abroad and thereby contribute to peace and individual freedom in the world community. If peace and freedom are among our goals, these then furnish another basis for public support of technological research in agriculture.

Some might say that this power to attain greater quantities of nonsubsistence goods and services for ourselves might be achieved by ways other than through technological research in agriculture, e.g., by territorial acquisition. However, if peace and freedom for peoples are among our goals, we cannot use this means and at the same time be consistent with our ends.

Others might say that public support of technological research in agriculture has indeed increased our welfare potential through larger quantities of nonsubsistence goods and services and through greater opportunities to advance world peace and freedom, but that these consequences serve only as bases for technological research in agriculture and not as bases for public support of such research. We can only

[5]The significance he attaches to "the power" is seen through this statement: "impotence may protect us from the worst results of wrong desires, but it can never yield us the satisfaction of right desires." See Boulding, K., Economic Analysis, 1948, p. 648.

[6]This statement might be questioned on the basis that as means increase relative to ends, more ends can be attained. Thus, means add to ends, which in turn stimulate the desire for more ends which require more means. Hence, a mad race develops between means and ends.

speculate on the technological changes that might have been wrought from the hands of entrepreneurs of agricultural firms had we relied solely on them. At this date, however, we can observe that the agricultural firm has remained small scale. Consequently, individual farmers do not possess the funds necessary for undertaking research on a scope to insure a high probability of invention or discovery.

PREDICTING THE CONSEQUENCES OF RESOURCES ALLOCATED TO TECHNOLOGICAL RESEARCH IN VARIOUS ALTERNATIVES IN AGRICULTURE

Economic theory contributes little to our understanding of the economic effects of technological change. The reason is that in traditional theory the state of the arts is given. Yet, technology is one of the most dynamic forces in our economy. An understanding of the process of technological change in order to predict its consequences is among the most challenging tasks facing the social sciences. Such knowledge would be particularly useful to administrators of resources for technological research in agriculture as a guide for efficient allocation of such resources.[7] The task here then is a consideration of models for predicting the consequences of resources allocated to technological research in agriculture, particularly those models which are structured to include the accumulative effects through time. One possible model is to predict outcomes for the agricultural industry on the basis of past consequences of resources allocated for technological research.

Model Based on Past Consequences of Resources Allocated for Technological Research

In constructing such a model we might wish to determine the relationship between technological change on the one hand and output, costs, and revenue for the industry on the other. One way of approaching this relationship is to relate changes in output over time to changes in revenue and costs.[8] Changes in output over time of course reflect not only the effects of technological change but also the effects of weather, government programs, and management. Considering output at the industry level and recording it in the form of five-year moving averages is likely to remove most of the weather effects on output. The effect of government programs on the aggregative output may very well be negligible since resources have been mostly free to shift among products.[9]

[7]Resource efficiency is defined to mean allocation of resources to attain the goals in question or to come as close as possible to attaining these goals.

[8]"Inferring this relationship" is perhaps more appropriate terminology than "approaching this relation" since change in technology for this model is known only by inference. The model includes no direct measure of technological change to which output, costs, and revenue can be related.

[9]Reference here is particularly to the acreage adjustment aspects of the program.

Moreover, output in the form of five-year moving averages gives these resources time to shift. Removal of the effects of management would be undesirable since management decides on adoption of innovations. Revenue and expenditures can be made to reflect changes in physical quantities by measuring them in constant dollars.

Changes in output, gross revenue, cash expenses, and net cash revenue for agriculture as a whole are outlined in Table 13.1. These data have been adjusted by the procedures just mentioned to reflect the output, revenue, and cost effects of technological change. During the first decade, technology appears to have been total output, total revenue, and total cost increasing. Net revenue also increased since total revenue increased by more than total costs. During the next decade, technology generally held total output and total revenue constant but decreased total cost. Hence it was net revenue increasing. During the 1932-36 period and since, technology has been total output, total revenue, and total cost increasing. On the whole, net revenue also increased as total revenue increased by more than total costs. During this latter period, particularly, increases in population and employment levels and upward shifts in consumer incomes have more than offset a price elasticity of demand of less than 1.0 for agricultural commodities, resulting in increasing total revenue for the period.[10] A price elasticity of less than unity operating without offsetting influences would cause a declining total revenue curve as an innovation increased output from one point in time to another (illustrated from Points A to B on Revenue Curve R_4 in Figure 13.1). However, when the demand schedule shifts upward and to the right, the total revenue curve shifts in a similar direction (R_1 to R_2, etc., in Figure 13.1). Such shifts can more than offset demand inelasticities to force increases in total revenue (Table 13.1 and Figure 13.1). Unit costs of production have decreased in the manner shown by Points S to V on TC_3 and TC_4 in Figure 13.1. Except for uncertainty considerations, innovations that fail to reduce unit costs would not be adopted, which explains the shift to the right of the total cost curves (TC_1, TC_2, etc., in Figure 13.1).

These data suggest that technological innovations in agriculture have for the most part been net revenue-increasing to the industry. Hence, if society's goal has been to increase total welfare potential and total income to agriculture, then past allocation of resources for technological research appears to have contributed to the attainment of this goal.

The efficiency of the above model for predicting the consequences of resources allocated for technological research in agriculture is likely to be low. It is a static type of model and likely to be more proficient in explaining ex post facto than in directing ex ante predictions.

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[10]Price supports and government payments have in effect increased the price elasticity of demand for agricultural commodities. However, since the proportion of total output moving into government hands in any one year is relatively small, an inelastic demand for agricultural commodities is considered to prevail.

Table 13.1. Total Marketings, Cash Receipts, Current Operating Expenses and Net Cash Receipts for U. S. Agriculture in Five-Year Moving Averages 1920-1955. (Total farm marketings are in terms of an index of output marketed with 1947-49 = 100, and receipts and expenditures are in terms of 1947-49 dollars.)

Period	Farm marketings (index)	Cash receipts-farm marketings and gov't. payments (millions)	Current farm operating expenses (millions)	Net cash receipts (millions)
20 - 24	62	$17,837	$ 7,583	$10,254
21 - 25	64	18,406	7,692	10,714
22 - 26	66	18,813	7,835	10,978
23 - 27	67	19,368	7,971	11,397
24 - 28	68	19,694	8,099	11,595
25 - 29	69	19,949	8,106	11,843
26 - 30	69	20,086	8,084	12,002
27 - 31	69	20,163	7,843	12,320
28 - 32	68	19,992	7,456	12,546
29 - 33	68	20,198	7,048	13,150
30 - 34	67	20,207	6,648	13,559
31 - 35	66	20,117	6,362	13,755
32 - 36	65	20,256	6,394	13,862
33 - 37	66	20,389	6,622	13,767
34 - 38	67	20,725	6,917	13,808
35 - 39	69	21,536	7,329	14,207
36 - 40	72	22,611	7,897	14,714
37 - 41	75	23,550	8,429	15,121
38 - 42	78	24,958	9,194	15,764
39 - 43	82	26,128	10,072	16,056
40 - 44	87	27,033	10,903	16,130
41 - 45	91	28,007	11,704	16,303
42 - 46	95	28,812	12,431	16,381
43 - 47	97	29,193	12,896	16,297
44 - 48	98	29,241	13,196	16,045
45 - 49	99	29,500	13,396	16,204
46 - 50	99	29,644	13,488	16,156
47 - 51	100	29,700	13,655	15,035
48 - 52	101	30,013	13,750	16,263
49 - 53	104	30,863	13,880	16,983
50 - 54	105	31,281	14,081	17,200
51 - 55	108	32,021	14,251	17,770

Source: FIS-159, U.S.D.A., July 17, 1956, and "Agricultural prices," Supplement No. 1, Crop Reporting Board, AMS, U.S.D.A., May, 1956.

We can predict successfully from it only if similar conditions prevail in the future as in the past and only if we have knowledge of these conditions — i.e., the major forces operating in the national economy, together with their effects, resource availabilities and allocations, people's expenditure patterns — and of the manner in which resources have been allocated for technological research and the extension of its results in agriculture. Lack of knowledge of these phenomena and of how they are related through time precludes action to cause their future recurrence for similar consequences. Moreover, since various types

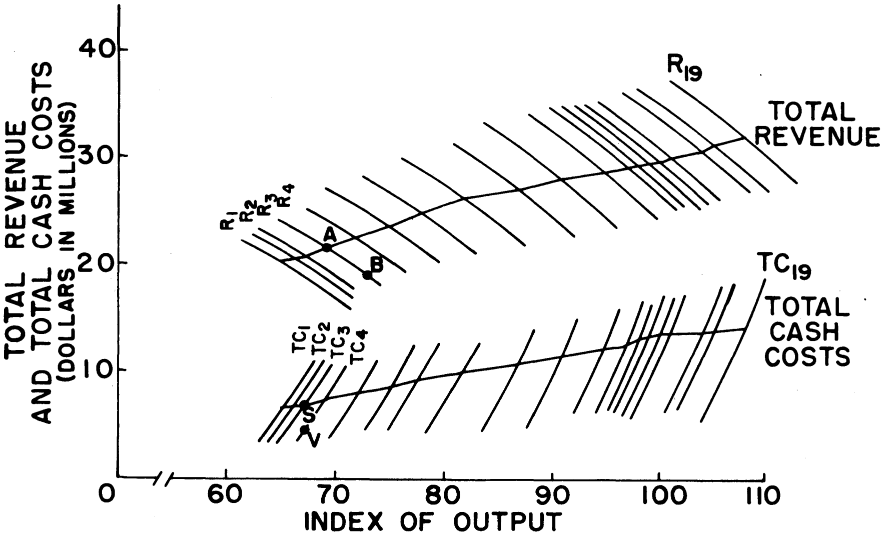

Fig. 13.1 - Output in relation to total revenue and total cash costs, U. S. agriculture, 1932-55 (source, Table 13.1).

of innovations may differ in their consequences, we may want a more specific type of prediction model.

Prediction Models for Various Types of Innovations Assuming Various Price Elasticities of Demand for Agricultural Commodities

Heady's models for predicting the consequences of different types of innovations are helpful in filling a void in economic theory.[11] Heady's models are geared to the industry level. The components of the models are a total revenue curve and two total cost schedules — one for the old technique and one for the new technique; these cost and revenue curves are then constructed with total output on the horizontal axis and dollars in revenue or costs on the vertical. The total revenue curve has an inclining portion to reflect revenue from the sale of commodities with price elasticities of demand greater than 1.0 and a declining portion to indicate revenue from sale of commodities with price elasticities of demand less than 1.0. Both cost schedules rise upward to the right, and the cost schedule for the new technique lies to the right of the schedule for the old, since with the exception of uncertainty consideration, all adopted innovations reduce unit costs. Heady classifies innovations in terms of their physical characteristics, their effects on output and on

[11]Reference here is to "Basic economic and welfare aspects of farm technological advance," Jour. Farm Econ., Vol. 31, May, 1949, and "Technological change and economic progress," Economics of Agricultural Production and Resource Use, Chap. 27.

costs. Thus, innovations are biological, mechanical, or biological-mechanical. They increase total output or hold total output constant. They are total cost-increasing or total cost-decreasing. Heady then sets up six situations which are constructed from varying demand conditions in combination with innovations which have different output and cost effects. From each of these situations, net revenue can then be predicted. Briefly the situations, the physical characteristics of the innovations, and the predicted effects on net revenues are as follows:

Situation	Physical characteristics	Predicted effect on net revenues
Demand elastic; total output and total cost-increasing innovation	Biological	Net revenue may or may not increase
Demand inelastic; total output and total cost-increasing innovation	Biological	Net revenue will decrease
Demand elastic; total output constant and total cost-decreasing innovation	Mechanical	Net revenue will increase
Demand inelastic; total output constant and total cost-decreasing innovation	Mechanical	Net revenue will increase
Demand elastic; total output-increasing and total cost-decreasing innovation	Biological-mechanical	Net revenue will increase
Demand inelastic; total output increasing and total cost-decreasing innovation	Biological-mechanical	Net revenue may or may not increase

Heady concludes that: (1) these various types of innovations have taken place side by side, but that available evidence indicates that aggregate farm technological advance has been of an output-increasing and likely of a total cost-increasing type; (2) this type of innovation, in combination with an aggregate elasticity of demand for farm products far less than 1.0, points to decreases in net revenue unless other forces increase demand and income; and (3) under any given demand situation, this type of innovation is likely to bring a lower net revenue than other types of innovations outlined.

Let us now examine these models to determine their efficiency in predicting the consequences of resources allocated to technological research among various alternatives in agriculture. If they are efficient, a research director should be able to say, for example, that if he allocates resources for research on biological innovations for commodities whose price elasticity of demand is less than 1.0, he can predict with considerable certainty that these innovations will be total output and total cost increasing but net revenue decreasing in the aggregate. We have already noted how forces such as increases in population and upward shifts in incomes can more than offset an inelastic demand and thereby reduce the likelihood of the prediction being correct — unless, of course, correct expectations were formulated about the ex ante effects of these forces. Moreover, these static models yield no information on when to expect changes in output, costs, and revenue. The rate of change in these variables is also vital in determining optimum resource allocation for technological research.

The success of our predicting the rate of change in these variables depends on knowledge of the whole technological process, i.e., knowledge of basic inquiry, invention, innovation, and imitation. Allocation of resources for research, say, in output-increasing techniques carries no assurance that output will increase in the aggregate. Perhaps knowledge in the basic sciences has not advanced sufficiently. Perhaps the inventor or applied scientist or experimentalist is out of touch with the concepts posited in the basic sciences. On the other hand, even if invention or discovery does take place, maybe innovation fails to materialize, or if innovation does take place, perhaps imitation does not. To predict the consequences of resources allocated over time for technological research requires knowledge of the whole technological process, of the steps in the process, and of the rate of change in the variables comprising the process. Let us, therefore, identify some of the major variables in each step of the process and see how these variables can be fashioned into a model.

Model Based on the Whole Technological Process

The foundation of technological change is basic inquiry. Fundamentally, research is undertaken to increase our understanding of our environment — both physical and social. Thus, basic inquiry is exploration of old or new phenomena because they are incompletely understood. Consequently, basic inquiry is theoretical and seeks knowledge for its own sake. The major variables contributing to the output (including its rate of accumulation) from basic inquiry are:

1. The amount of accumulated knowledge about fundamental relationships or processes among phenomena.
2. The number and quality of scientists who are positing basic concepts.[12] Imagination, together with intense devotion to their work, appear among the most important qualities.

[12]Man is an important variable in this and the succeeding step in the technological process. Actually, one might entertain the position that research resources should be allocated to men rather than to projects. It has been pointed out that the tendency is to do exactly the reverse and that this procedure stems from a belief in centralized control and planning — that we must have a coordinated research plan and avoid duplication. Yet, duplication is exactly what needs to be emphasized because new ideas are likely to develop only as a number of people with different viewpoints, insights, and interests investigate the same area. On this basis, an administrator of resources for technological research would allocate resources to the men where he expects highest marginal productivity. (The point as developed here follows M. Friedman's in Amer. Econ. Rev., Vol. 43, May, 1953, p. 447).

3. The environment in which scientists work. Elements in this environment which contribute to the productivity of scientists are relief from routine tasks, sufficient funds, and a spirit of freedom which fosters basic inquiry.

Although research is undertaken primarily to increase our understanding or knowledge, we are likely to draw upon this knowledge in finding operative solutions to our problems. Thus, a second step in the technological process is characterized by the experimentalist, the inventor or discoverer, the engineer, the applied scientist. The men working in this area translate the theory from basic inquiry into invention or discovery for practical use.

The major variables contributing to output in the form of invention or discovery are:

1. The extent of communication with the men and the work in basic inquiry, e.g., the extent of communication between the researcher in animal nutrition and the chemist or between the researcher in plant or animal breeding and the geneticist.

2. The amount of funds.

3. The number and quality of applied scientists. Qualities essential to high productivity are inventiveness, an appreciation of basic inquiry, a desire to make knowledge operative in solution of problems, and a knowledge of practical problems.

4. The stock of accumulated knowledge in basic inquiry.

Innovation is the stage in the technological process wherein the changes in technological possibilities, which have been fashioned by the inventors or discovers, are put into use or adopted by one or more entrepreneurs.[13] These entrepreneurs are thus technological leaders.

Variables which determine innovation are:

1. The stock of inventions or discoveries from which to draw.

2. The level of technological leadership. A high level of technological leadership may be characterized by those entrepreneurs who: (a) have a strong desire for improvements in production and therefore exert special effort to learn about new inventions and discoveries, (b) attain greater utility from possible gains as a result of being first in adopting new technology than disutility of possible losses from adoption, (c) are young to middle-aged, and (d) have aggressiveness and/or ability to formulate expectations in line with realizations.

3. The degree of risk or uncertainty in committing capital to specialized forms.

4. The resource requirements of the innovation. Some innovations can be adopted with small increases in current operating expenses, while others require sizable capital outlays. Moreover, some innovations require not only the initial capital outlay but lead to other capital expenditures, i.e., to major modifications in the plant; illustrations are

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[13]Available data point to a sizable group of innovators in the farm population. According to the Interstate Managerial Study, 36 percent of the farm operators questioned were willing to be first in trying out an innovation.

substitution of mechanical for horsepower or adoption of soil conserving practices.

5. The expected flow of returns from the innovation, i.e., how profitable it is expected to be and the time flow of these returns. Some innovations may return the investment and more within the year, while others return the investment only over a period of years, and the present value of future returns becomes important in measuring profitability.

6. The existing resource patterns and resource availabilities. The amount of capital sunk in old techniques may deter innovation. On the other hand, a growing supply of capital is likely to encourage innovation.

7. The nature of the industry. In a declining industry, a new technique is likely to be adopted only if the average total cost of it is less than the average variable cost of operating with present techniques. On the other hand, in a growing industry, a new technique is likely to be adopted whenever the average total cost of it is less than the average total cost of operating with new equipment of the old type.[14] The degree of competition in the industry can also encourage or deter innovation. Some argue that the competitive structure of agriculture encourages innovation. The argument is that competition forces farmers to adopt new techniques since failure to adopt places them at a disadvantage relative to other farmers. Imperfectly competitive industry, on the other hand, may postpone innovation in order to maintain the capital value of an obsolete investment.[15] This argument may be more applicable to imitation than innovation. Competition may foster or encourage rather than force innovation. In industries with price elasticity of demand of less than unity, innovators may be aware of the likelihood of abnormal profits from new techniques until imitation proceeds to the point where increased output returns less revenue.

8. The level of economic activity and population status. A growing population along with an increasing level of national income and employment is likely to be more conducive to innovation than a constant or declining population coupled with deflationary pressures which make holding money more attractive than investing in capital.

9. The tax system. Taxes may deter or encourage innovation depending on whether capital write-offs are in line with obsolescence.

10. The extent and intensity of organized effort expended in bringing information about inventions and discoveries to innovating entrepreneurs. In agriculture, for example, the Extension Service is an organization which can perform this function.

Imitation in the technological process is the step when others follow the innovators. Imitation is diffusion in the application of new technology by entrepreneurs.[16] The extent of imitation determines whether there will be any substantial effects through time from resources allocated to basic inquiry, invention, and innovation.

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[14]See Brozen, V., "Invention, innovation and imitation," Amer. Econ. Rev., Vol. 41, May, 1951, p. 246.

[15]See Schultz, T. W., The Economic Organization of Agriculture, Ch. 7, p. 112.

[16]According to data from the Interstate Managerial Study, 50 percent of the farmers questioned are in the category of imitators.

The major variables determining innovation appear equally relevant as determinants of imitation. However, we might expand upon the discussion of some of these variables and add a few more. Resource availabilities and resource requirements of new technology are of particular importance to imitation because of the wide variation in resource availability among agricultural entrepreneurs. This wide variation in resource availability can force entrepreneurs to operate on different iso-product contours. For instance, in Figure 13.2, some managers, because of resource availability, Oa of labor and Or of capital, may be forced to operate on iso-product contour I_1 at the point where it is intersected by Ray 1 (R_1). These entrepreneurs may be forced to operate at this point even though factor price ratios indicate greater profits by operating where R_2 intersects I, or where R_3 intersects I_2. Other managers may find operating where R_2 or R_3 intersect I_2 as most economical because of more ample resource supplies. Innovations giving rise to rays between R_2 and R_3, will not be imitated by capital-short managers. However, innovations giving rise to rays lying between R_1 and R_2 (R_4 for example) can have strong likelihood of being imitated since a small increase in capital availability (rv) makes

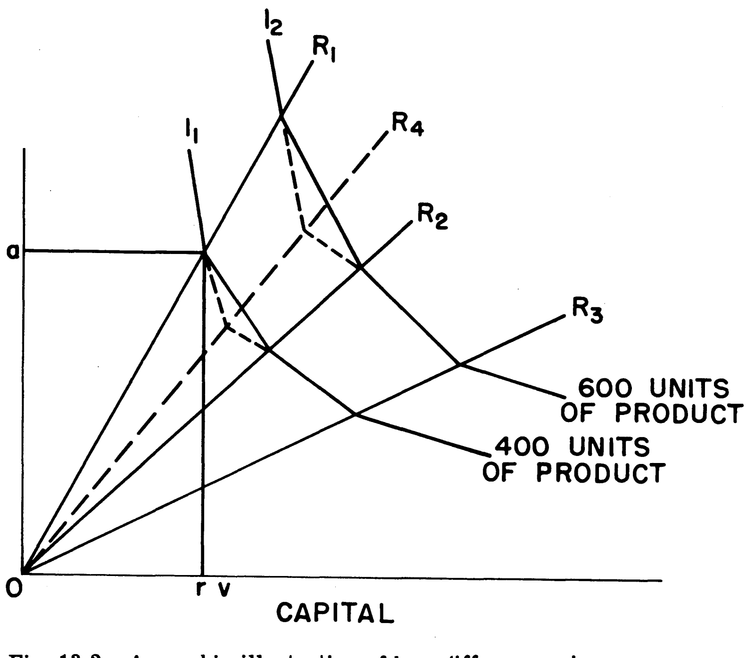

Fig. 13.2 - A graphic illustration of how differences in resource availabilities may influence choice of production techniques and amount produced. (R_1, R_2, and R_4 are rays representing different production techniques available at a given point in time. I_1 and I_2 are iso-product contours. R_4 represents a new production technique, which shifts the old iso-product contours to the new positions shown.)

imitation possible. The large increase in mechanization in the Southeast after World War II illustrates how an innovation failed to be imitated in a large segment of the country until capital supplies increased.

Other variables, aside from those already mentioned, which are determinants of imitation are:

1. Knowledge of credit capital sources. Lack of such knowledge may deter imitation.

2. Levels of managerial training or ability. High management levels are expected to encourage imitation.

3. Marginal utility for gains or marginal disutility for losses. Imitators are expected to have a lower marginal utility for gains or a higher marginal disutility for losses than innovators.

4. Communication. Factors, such as social and economic class divisions or low educational levels, act as barriers in communication.

5. Differences in goals or ends. Amish settlements, for instance, have resisted imitation in technology for a considerable span of years.

We have outlined a number of variables as major determinants of the whole technological process. The answer to the question of whether they are indeed the major determinants awaits fuller knowledge than we now possess. The same can be said for the manner in which the variables are related through time in the whole technological process. But until we do have fuller knowledge of the whole process, we are hardly in a position to predict accurately the consequences of allocating resources to technological research and to the extension of research output. We can only speculate and say that perhaps more funds should be allocated to basic inquiry and less to invention or discovery; or perhaps less should be spent on imitation and more on innovation. Perhaps a lag in imitation is necessary so innovators can realize abnormal profits as a return for taking innovating risks; or perhaps society should assume these risks and innovators would then receive the abnormal profits without risk costs; society could then redistribute these gains through the tax system. Again, perhaps, capital accumulation by entrepreneurs is more important in the technological process than any organized effort to inform entrepreneurs of new inventions or discoveries.

We should prefer more than conjecture in these matters. We should like to be able to predict, with some assurance of being correct, the consequences of allocating resources to technological research. A prediction model, which includes all the steps in the technological process, might be formulated somewhat as follows:

$Y = f(X_1, X_2, X_3, X_4)$ where
Y = the technological outcome
X_1 = basic inquiry
X_2 = invention
X_3 = innovation
X_4 = imitation

Each of the independent variables would contribute in varying amounts to the accumulated outcome in Y and these amounts can be designated by constants, a, b, c, and d for X_1, X_2, X_3, and X_4, respectively. Since technological change in one time period is influenced by changes in the independent variables in the preceding time period, time can be introduced by considering a differential equation. Thus, change in Y in time period, t_1, can be expressed as follows:

$$\frac{dY}{dt_1} = a' \frac{dX_1}{dt_0} + b' \frac{dX_2}{dt_0} + c' \frac{dX_3}{dt_0} + d' \frac{dX_4}{dt_0}$$

The change in each independent variable in t_0 is a function of the parameters previously outlined along with changes in the preceding step in the technological process. Thus, the change in X_4 (imitation) in t_0 can be written as a function of the following parameters:

$$\frac{dX_4}{dt_0} = f(\text{stock of inventions, level of technological leadership, degree of risk or uncertainty in innovating, --------- } \frac{dX_3}{dt_0})$$

Similarly, the changes in the other independent variables in t_0 can be expressed as functions:

$$\frac{dX_3}{dt_0} = f(\text{expected level of economic activity, expected population status, expected flow of returns from the innovation, -- } \frac{dX_2}{dt_0})$$

$$\frac{dX_2}{dt_0} = f(\text{extent of communication with work in basic inquiry, amount of funds, ------- } \frac{dX_1}{dt_0})$$

$$\frac{dX_1}{dt_0} = f(\text{amount of accumulated knowledge, number and quality of scientists, -----})$$

Change in Y in time period, t_2, can then be expressed as follows:

$$\frac{dY}{dt_2} = a'' \frac{dX_1}{dt_1} + b'' \frac{dX_2}{dt_1} + c'' \frac{dX_3}{dt_1} + d'' \frac{dX_4}{dt_1}$$

The change in each independent variable in t_1 is then determined in the following manner:

$$\frac{dX_1}{dt_1} = f(\text{amount of accumulated knowledge in } t_1\text{, number and quality of scientists in } t_1\text{, ---------, } \frac{dX_1}{dt_0})$$

$$\frac{dX_2}{dt_1} = f(\text{extent of communication with work in basic inquiry in } t_1\text{, amount of funds in } t_1\text{, -------, } \frac{dX_1}{dt_0}, \frac{dX_1}{dt_1}, \frac{dX_2}{dt_0})$$

$$\frac{dX_3}{dt_1} = f(\text{expected level of economic activity, expected population status, expected flow of returns from the innovation, ----, } \frac{dX_2}{dt_0}, \frac{dX_2}{dt_1}, \frac{dX_3}{dt_0})$$

$$\frac{dX_4}{dt_1} = f(\text{stock of inventions in } t_1\text{, level of technological leadership in } t_1\text{, degree of risk in imitating, -----, } \frac{dX_3}{dt_0}, \frac{dX_3}{dt_1}, \frac{dX_4}{dt_0})$$

In order to predict the consequences of allocating resources to technological research, an understanding of the manner in which the model relates the variables through time is essential.

The above model recognizes that all new technology is not only dependent upon old technologies, but also that there may be a logical development pattern for technological change. The model with empirical parameters seeks to predict the accumulated effects of technological change from knowledge of this pattern.

Because of the difficulties involved in establishing the necessary parameters, the prediction model just outlined may be of considerable concern to the applied scientist. But I am quite sure also that we will all admit that technological change is a complex process and that, therefore, constructing a model to predict this change with an acceptable degree of accuracy is far from simple. Since considerable time would be required to test such a model, we might turn to another model which may give us some current insights on how to allocate resources for technological research.[17]

Model Based on No Further Technological Research

The assumptions or conditions underlying this model are:

1. Technology in agriculture is held constant, i.e., no new techniques are introduced, but choices remain among known techniques.
2. Continued increase in population.
3. Present trade restrictions.

With these assumptions we might then postulate the immediate and long-run effects. In the immediate future, output in agriculture will continue to increase. This increase stems from further diffusion of knowledge about techniques currently known to researchers and/or innovators. The proportional increases in agricultural output will depend in part on the relative stocks of inventions and discoveries which now exist for different products.

In the long run, the following conditions can be expected to materialize:

1. Population begins to press against the food supply as population increases with a diminishing food supply.
2. Food prices will increase.[18]
3. Labor resources will move into agriculture along with capital for the purchase of land and other resources.
4. Production functions in agriculture will drop to lower levels as

[17]This proposal is made not with the idea of abandoning the model based on the whole technological process. The suggestion is made only for the purpose of considering another model which may offer some guidance in the short run. In spite of the complexity of the technological process model, certainly some resources "should" be allocated now to a study of the process itself. To date, sociologists have taken the leading role in studying the process.

[18]If consumer incomes are changing, both price and income elasticities of demand will need to be considered in determining the relative price changes for different foods.

ravages from insect pests and diseases increase. Cost per unit of output in agriculture will increase, but the increased value productivity of resources will probably more than offset this increase in costs.

5. The marginal physical productivity of resources in industry will increase but the marginal value productivity will decrease.

6. Farms will become smaller and more capital and labor will be needed to produce a smaller, or the same, output as before.

7. Less resources will be available for secondary and tertiary production. Hence, living levels will decline. Diets will gradually deteriorate as population exerts greater and greater pressure on food. As more and more people fail to satisfy their food needs through meats, fruits, and vegetables, demand will shift in the direction of food grains, potatoes, and lentils.[19] If, at this point, funds were again allocated to technological research, the emphasis in this research would be on output-increasing techniques for these products.

These conditions may suggest in a general way how resources for technological research need to be reallocated. Certainly we are far from the point where additional resources for technological research are needed for output-increasing techniques for food grains, potatoes, and dry lentils. On the contrary, consumer demand and surpluses suggest fewer resources for technological research in production of food grains, dry lentils, and potatoes, together with sugar and cotton. Since, under our assumed conditions, the pinch would come first for fruits, vegetables, and livestock products, and since consumers, through the market, indicate a relatively high order of preference for these products, additional resources for technological research are suggested for these and complementary primary products, such as feed grains and forages. Output-increasing techniques should be emphasized for these products — for livestock not in the sense of increasing output per unit of time but per unit of feed.

CONCLUSIONS

The economics of technological change remains as one of the least developed areas in economics — both in theory and application. Yet, because technological change is one of the most dynamic forces in our economy, its impact on socio-economic processes is tremendous. Hence, lack of knowledge of the technological process and its consequences is one of the most significant problems in economics, particularly, and in social science, generally. For this reason, the temptation is great for us to work on a problem of this magnitude and complexity. Perhaps, we should seriously consider resisting this temptation because as Friedman has pointed out: "Economics can be and remain a cumulative science only if little bits and pieces can be done right so

[19]Diets including meats, fruits, and vegetables are generally regarded as superior in quality although less efficient in use of resources for producing calories.

that these can serve as firm bricks on which to rest the structure."[20] In a study of the economics of technological change there appears to be a need to shape numerous little bits and pieces into firm bricks before we can build a structure which can give us the power to predict the consequences of allocating resources to technological research in agriculture.

[20]Friedman, M., From a discussion paper in Amer. Econ. Rev., Vol. 43, May, 1953, p. 445. von Neumann and Morgenstern have advanced a similar idea by saying: "the great progress in every science came when, in the study of problems which were modest as compared with ultimate aims, methods were developed which could be extended further and further." (see Amer. Econ. Rev., Vol. 43, May, 1953, p. 428.

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Discussion

As Harold Jensen effectively points out, we as researchers seek to discover and formulate basic relationships in order that we may improve our capacity to project, predict. In this discussion we seek to determine the probable consequences of making or not making certain biological, mechanical, and related changes. As an essential part of our analysis, we need to predict probable rates of adoption of the technological innovations which we evaluate.

No single mechanical, biological, or other technological development can be analyzed as a separate entity. New technological developments tend to come to us in chunks — not in integrated production, processing, or distribution systems. A part of the genius of successful management is the assimilation, integration, and synthesis of separate building blocks into processes not previously in existence.

One of the objectives of this conference is to produce some fairly specific research proposals. To this end the following are suggested.

To help us improve our predictive capacity, to provide greater opportunity for creative research in technological innovation, some of us feel that the farm counterpart of industry's pilot plant is needed in agriculture. This pilot plant probably should:

1. Become a laboratory for integration of modern technology into new systems of farm organization and operation — a vehicle for creating and testing whole new systems of production (and perhaps of marketing).
2. Be a research, not a demonstration unit.
3. Be under private, not public, ownership.
4. Be operated by superior, not average, management.
5. Be financed (perhaps by a foundation) with a guaranteed income to the private owner who would also share in the profits.[1]

Details remain to be worked out by thoughtful, creative minds. The potential could be substantial. If a research step of this size cannot be undertaken, maybe we should substitute careful case studies of individual innovators. Maybe we should do both. To the individual firm the capital requirements and learning costs of applying new technological developments are high. Perhaps the pilot plant idea can: (1) improve

[1]This admittedly creates an artificial situation whereby many risk and uncertainty considerations are removed.

the efficiency of the development and integration process and (b) give us coefficients for budgeting and programming in order that the research educator, innovator, and imitator can more accurately predict the consequences of alternative courses of action.

Now let us turn to a related research area.

Technological developments do not stop with production. In fact, we might reason thus:

1. Technological research tends to produce means whereby man gains greater control over environmental forces. Some of the non-price risks and uncertainties are removed. The physical product likely to result from following a given production process and practice can be predicted with greater certainty. Broiler production is cited as a case in point. Time, form, quality of output from given feed, labor, housing, management, and related inputs are accurately predictable.

2. When production of large quantities of highly standardized food products becomes economically possible, (either from individually small or large production firms) mass distribution agencies become interested.

3. If farm producers are unwilling to meet mass distribution requirements — time, form, place, quantity, quality, package — assembly or distribution agencies may stand ready to enter the production field. This may be direct (as with production of some fruits and vegetables for processing) or indirect (as in contractual arrangements). A key point of entry seems to be through provision of capital.

This brings us to the need for research in the financing of technological innovations in agriculture. What are the alternative methods for channeling needed capital into agricultural production? What are the probable consequences <u>if</u> capital for innovation flows into farm production through:

1. Machinery dealers or manufacturers (leasing, not selling machines).

2. Public utilities, corporate or cooperative (providing producers with materials-handling equipment, appliances, along with the electrical energy).

3. Lending institutions (public or private) by assigning to real estate a <u>permanent</u> debt load.

4. Service corporations or cooperatives which erect farm structures, construct irrigation installations and other improvements, and lease them to farmers.

5. Increased absentee ownership, resulting in tenant operation of a larger percentage of our farms.

6. Vertically integrated farm supply, food processing, or food distribution firms.

In the years ahead the route through which the capital flows into farm production may be:

1. A key to rate of adoption of technological developments, change, and resulting adjustments.

2. A determinant of the bargaining power of the farm producer in the market place.

3. An indicator of the nature of the future structure of the farm firm itself.

Yes, research in this broad area involves foresight. Historical analysis will not suffice. We may be forced to "make more of our own data" through pilot plant operation or sheer deduction. This, however, is legitimate, desirable activity for agricultural economists.