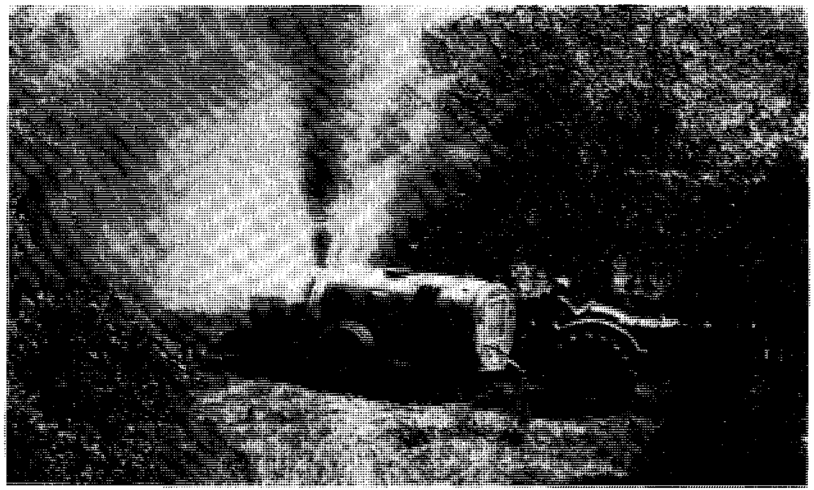

Spraying the orchard, vintage 1900 (left) *vs.* spraying with today's highly sophisticated chemicals and equipment

Technological Change and Resource Requirements in American Agriculture

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An increasing share of the national product is being devoted to research and development leading to technical innovation. The effect of such innovation is to reduce, below the levels that would otherwise be required, the inputs of resources necessary to achieve successively higher levels of output. As expenditures on research and development continue to rise, it becomes increasingly important to evaluate the contribution which research expenditures are making to national output and to the output of the several segments of the economy.

This is particularly true in the case of agriculture. Agriculture has been a major recipient of state and federal funds devoted to research and development. Private firms in the farm equipment, farm chemical, and other farm supply industries have also devoted substantial funds to research and development. The effect has been to create what the Secretary of Agriculture has termed a "technological revolution" in American agriculture. Instead of worrying about the "pressure of population on food supplies," the major farm policy problem in recent years has been how to deal with the "pressure of food supplies on population."

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The discussion that follows will seek to answer four questions concerning the technological revolution in American agriculture. *First,* how does agriculture compare with the rest of the economy in its rate of application of new technology? *Second,* how have the effects of technological change on farm output differed from region to region among the nation's several major agricultural regions? *Third,* what effect will continued technological change have on input requirements in American agriculture by 1975? *Fourth,* what are some of the agricultural policy implications of continuing rapid technological change?

Until recently the impact of technological change was measured mainly in terms of its impact on "labor productivity"—output per unit of labor input. Recognition of the biases inherent in this approach has led to an approach based on changes in "total productivity"—output per unit of total input, including not only labor, but also capital and land inputs and current operating expenses. This approach also has a number of limitations, particularly those associated with the problem of index number construction and with the effect of changes in the technical limits (or rates) within which inputs can be substituted one for another to achieve a particular level of output.

The "index number problem" stems from the fact that when two or more inputs (or products) are combined to form a measure of total input (or output) the result will depend upon the particular weights used to aggregate the several input (or output) components. Price weights based on average prices for some base period, say 1935–1939 or 1947–1949, are usually used to combine land, labor, capital, and current operating expenses into a measure of total inputs and to combine the several products produced into a measure of total output. If a major shift in the prices of inputs relative to one another or in the prices of products relative to one another occurs during the period being studied, then indexes based on 1935–1939 price weights will differ from indexes based, for example, on 1947–1949 weights. The effect of "index number bias" is magnified if changes in technology have been such as to change drastically the proportions in which the several inputs are combined, or if changes in consumer tastes have dictated drastic changes in the combination of products produced.

Statisticians have been unable to devise any "ideal" solution to the "index number problem." It is possible to check the degree of bias introduced by the complex of factors involved, however, by constructing indexes of input and output based on 1935–1939 (or any other "beginning period") weights and on 1947–1949 (or any other "end period") weights, and comparing the results. Ralph Loomis has presented an excellent illustration of the effect of "index number bias" in his article on "Effect of Weight Period Selection on Measurement of Agricultural Production Inputs" in the October, 1957 issue of *Agricultural Economics Research*. In the case of the indexes used in this study, the alternative base period tests indicate that the magnitude of "index number bias" is not of sufficient magnitude to preclude the use of change in output per unit of total input as an effective indicator of the impact of technological change.

The "total productivity" approach has been successfully employed in studies of the total economy by Kendrick, Abromovits, and their associates at the National Bureau of Economic Research, and in studies of technological change in agriculture by Glen Barton of the U. S. Department of Agriculture and T. W. Schultz and his associates at the University of Chicago. Raymond Ewell used the same general approach in his survey on the "Role of Research in Economic Growth" in the July 18, 1955, issue of *Chemical & Engineering News*.

The "total productivity" approach is also being used in our work at Purdue on measuring the effects of technological change in agriculture. There, however, we have modified the approach by introducing weighting procedures which are more consistent with research results obtained by agricultural "production economists."

Table I. Average Annual Percentage Rates of Change in Output Per Unit of Total Input, Output Per Unit of Labor Input, and Output Per Unit of Capital Input in Selected Industries, 1899–1953

(Output measured in terms of value added)

	Long period, 1899–1953	Two major subperiods 1899–1919	Two major subperiods 1919–53	Two recent subperiods 1919–48	Two recent subperiods 1948–53
1. Output per unit of total input in:					
Total private domestic economy	1.7	1.1	2.2	...	...
Agriculture[a]	0.9	0.0	1.4	1.5	1.1
Manufacturing[b]	0.9	−0.5	...	1.8	...
Mining[c]	...	...	...	...	...
2. Output per unit of labor input in:					
Total private domestic economy	1.9	1.4	2.3	...	...
Agriculture[a]	1.6	0.5	2.3	2.2	2.7
Manufacturing[b]	1.8	0.8	...	2.4	...
Mining[c]	3.1	2.3	...	3.9	...
3. Output per unit of capital input in:					
Total private domestic economy	1.1	0.2	1.7	...	...
Agriculture[a]	0.2	−0.5	0.6	0.8	−0.2
Manufacturing[b]	0.3	−1.2	...	1.5	...
Mining[c]	0.1	−1.2	...	2.2	...

[a] Data for agriculture are for 1899–1955, 1919–55, and 1948–55 rather than as indicated in the headings.
[b] Data for manufacturing are for 1900–48 and 1900–19 rather than as indicated in the headings.
[c] Data for mining are for 1890–1948 and 1890–1919 rather than as indicated in the headings.

SOURCES: Rates of change for total private domestic economy are from Kendrick, John W., *Productivity Trends: Capital and Labor,* Occasional Paper 53, National Bureau of Economic Research, Inc., 1956. Rates of change for other sectors are from Ruttan, V. W., *Journal of Farm Economics*, vol. XXXIX, December 1957.

Agriculture Compares Favorably With the Rest of the Economy

Of special interest to those concerned with agriculture is the fact that growth in the total "net" input-output ratio in agriculture compares favorably with growth in the total "net" input-output ratio in manufacturing throughout the entire period since 1899. Both sectors have experienced a rate of growth of about 0.9% per year. Neither agriculture nor manufacturing experienced any gain in the total input-output ratio between 1899 and 1919. During the period between 1919 and 1948, both sectors experienced an increasingly rapid rate of growth. But contrary to some rather widely held opinion, agriculture, at least, has experienced some decline in the rate of growth in output per unit of total "net" input in the years since 1948 (Table I).

Furthermore, output per unit of total input in both agriculture and manufacturing has lagged relative to other major industrial sectors of the economy throughout the entire period since the turn of the century. Kendrick's studies show that the mining, transportation, communication, and utilities industries have experienced even more rapid increases in the "net" input-output ratios than agriculture or manufacturing. The trade and service industries have, in general, experienced somewhat slower rates of growth.

Since 1919 a remarkable shift has occurred in the American economy. Technological change has become capital-saving as well as labor-saving. Output has expanded relative to inputs of both capital and labor. The consequence has been a marked increase in the rate of growth per unit of total input. Agriculture has participated in this shift along with manufacturing and the other major industrial sectors.

What factors have been responsible for the emergence of capital-saving innovations on a substantial scale during the last four decades? A definite answer to the question is not available. My own hypothesis is that the relative importance of capital-saving innovation during the second quarter of this century has been related to a "lumpiness" in the timing of a number of basic scientific and technical developments. Historically, scientific advance and technical innovation have not occurred in a steady flow. Periods of rapid progress have alternated with periods when progress has been slow and difficult.

The first industrial or agricultural applications of basic scientific or technical advances tend to be primarily labor saving. After these basic advances have been translated into workable production processes, and the technology becomes widely disseminated, continuous experimentation and improvement take place. During this later stage of application, increases in output per unit of capital input become increasingly important.

The emergence of capital-saving innovation during this later stage stems from a dual foundation. First, the initial technical applications of the basic scientific advances are poorly engineered and are integrated into the total production system in a rather inefficient manner. Widespread adoption of the tractor for general farming operations, for example, had to await the development of more compact, more efficient, and less expensive machines than the tractors that were first used in plowing and harvesting on the wheat farms of the Great Plains and the Pacific Northwest. Capital saving is thus a natural consequence of engineering and organizational refinements in the production processes. Second, as labor saving innovations are introduced, capital inputs become a larger share of total inputs. This adds an economic as well as a technical basis for capital-saving innovations during the latter stages.

In retrospect the characteristic patterns of technological change in the period before 1919—*with decreases in output per unit of capital input largely offsetting increase in output per unit of labor input*—clarify a number of agricultural policy issues. Most obvious for agriculture is the relationship between the role of technological change and the choice of the 1910-1914 parity base. Between 1899 and 1919 there was virtually no increase of "net" output per unit of total "net" input in agriculture. Technological change in agriculture was able to do little more than offset the effect of diminishing returns—the tendency of yields to decline as less productive land is brought into cultivation and as natural fertility is reduced. Sharp increases in farm prices were required to achieve the expansion in farm output required by a rapidly expanding national economy. The decline in output per unit of total input in agriculture prior to 1919, reflected in a rise in prices paid to farmers and in prices paid by urban consumers during much of the 1899-1919 period, was also undoubtedly an important factor behind the growing concern with the conservation problem. With food prices rising faster than wages, it was not too difficult to convince urban consumers of the need for conservation. In more recent years, the rapid increase in output per unit of total input, reflected in growing "pressure of food supplies on population," has probably been an important factor in placing the conservation drive on more rational economic footing.

All Regions Have Not Shared Equally

Interest in regional comparisons of the change in output per unit of total input stems mainly from a single concern: What would be the implications for the nation's agricultural policy if a major share of resource savings—that is savings in labor and capital inputs—due to technological change were concentrated in one or a few regions? Studies by T. W. Schultz have shown, for example, that agricultural research funds have been concentrated in such a manner as to favor those states in the North Central and Pacific regions in which agriculture is already most highly developed.

The data in Table II reflect the effect of this concentration of research effort. The North Central and Pacific regions together accounted for between 55 and 60% of the total resource savings resulting from technological change in American agriculture between 1925 and 1955.

Table II. Regional Differences in the Contribution of Technological Change to Farm Output, 1925–1927 to 1953–1955

Region	% age of total resource savings resulting from technological change between 1925 and 1955: 1925–27 weights	1953–55 weights	% age of United States net farm output in current dollars in: 1925–27	1953–55
Northeast	6.9	5.3	9.7	7.8
North Central	40.3	40.5	42.3	41.5
South	33.0	27.6	34.7	32.5
Mountain	5.4	5.9	5.7	6.5
Pacific	14.3	20.7	7.7	11.7
United States	100.0	100.0	100.0	100.0

Source: Stout, T. T., and Ruttan, V. W., *Journal of Farm Economics*, vol. XL, May 1958, p. 201.

The pattern of change was, however, somewhat different from what might have been expected. Only in the Pacific region was the rate of increase in both net output and in output per unit of input sufficiently rapid to raise the region's share of resource savings sharply above its share of output. With only 7.7% of the nation's net farm output in 1925-1927 and 11.7% in 1953-1955, the Pacific region accounted for between 14.3 and 20.7% of the nation's total agricultural resource savings due to technological change between 1925 and 1955.

The North Central region did not depart sharply from the national average in either growth of net output or output per unit of input. The region accounted for approximately 42% of the nation's net farm output in both 1925-1927 and 1953-1955 and between 40 and 41% of the nation's total resource savings resulting from technological change between 1925 and 1955.

Approximately identical rates of technological change were observed in both the South and in the North Central region. However, the proportion of the nation's resource savings which occurred in the South fell somewhat below the South's share of net output as net farm output in the South declined from 34.7 per cent of the national total in 1925-1927 to 32.5 per cent in 1953-1955.

The smallest increases in output per unit of total input occurred in the Northeast and in the Mountain region. In the Northeast this appears to have been primarily associated with a decline in output relative to other areas. In the Mountain region output increased fairly rapidly, but the data indicate that increased inputs played a considerably larger role and technological change a considerably smaller role in achieving this growth in output than in the other regions.

Future Input Requirements

It is not possible to *predict* the precise level of farm output that will be attained by 1975 or any other future date. Nor can the exact combination of inputs that will be used to produce a particular level of output be specified precisely.

It is possible, however, to arrive at a fairly reasonable output *projection* for the mid-1970's. It is also possible, without specifying the rate of technological change that will actually be achieved during the next decade and a half, to analyze the probable effects of alternative rates of technological change on the inputs required to produce a given level of output. The rate of technological change that will actually be achieved will, of course, depend upon many factors over which decisions have yet to be made—the financial resources to be devoted to research and development, and the quality of research personnel which the colleges send into industry, for example—as well as the many intangible elements which enter into the effectiveness of basic and applied research.

Since *projections*, in contrast to *predictions*, serve to illustrate the consequences of decisions and actions over which some degree of control still exists, their most effective use is in guiding policy. The challenge is, for example, to bring about a level of technological change which is consistent with both the required level of farm output and feasible changes in land, labor, and capital inputs in American agriculture.

Four pairs of alternative output and input projections for 1975 are compared in Table III. The projected index of farm output of 160 (1950 = 100) is somewhat higher than recent projections of the U. S. Department of Agriculture, chiefly because of the larger population which now seems likely by 1975.

Four basic technological change

possibilities are identified. For purposes of contrast, input requirements are first shown for the situation that would exist if technical change—growth in output per unit of total input—completely ceased. Extremely large quantities of capital and current operating expenses would have to be employed, along with a rather constant quantity of land and some additional decline in farm labor, in order to achieve the required level of farm output.

In the second situation—identified as "slow technical progress"—a rate of technological change similar to the average rate since 1910–1914 is assumed. Even with this fairly modest rate of change (see Table III), substantial reductions in input requirements are indicated as compared to the zero technological change situation. "Rapid technical progress"—proceeding at a rate similar to that of the last three decades—results in further declines in input requirements, but a larger share of the decline is felt in terms of declining labor requirements and less in terms of declining capital and current input requirements.

In the last situation—identified as "very rapid technical progress"—the consequences of a rate of technical progress which would permit aggregate inputs to remain unchanged between 1950 and 1975 are examined. Although total inputs are held at the 1950 level, substitution of capital and current operating expenses for labor is projected.

Within each of the four major projections, a situation characterized as "high" and "low" level land inputs is presented. Considerable controversy has surrounded the question of future land requirements. Part of this controversy seems related to the traditional practice of stating future output requirements in terms of acreage equivalents—"by 1975 increased food and fiber requirements will require the equivalent of 50 million additional acres of land"—instead of dealing explicitly with the contribution of technological change to farm output. Most projections have assumed some increase in land inputs stemming from irrigation and reclamation developments. On the other hand, land inputs have actually declined slightly in recent years. Assuming a maximum decline of land inputs to an index of 90 and a maximum rise to an index of 110 probably brackets the reasonable range of alternatives, and serves to illustrate the effects of alternative land policies on requirements for other inputs.

Of the eight projections presented in Table III, projections D and E appear to be the most reasonable at the present time. If the rate of technological change is not pushed above the long-term 1910–1950 rate assumed in projection D, conversion of pasture land to cropland, and irrigation and reclamation projects designed to expand land inputs, will probably appear rather attractive. If the rate of technological change can be pushed to the level assumed in projection E, measures to add additional land inputs may not even fully replace land being removed from agricultural use by highways, airports, and "suburban sprawl." In either case costs of additional land inputs will have to be carefully compared to the cost of achieving increased farm output in other ways. Can, for example, a given increase in output be achieved more effectively or economically by investment in land reclamation or by investment in research effort designed to develop more efficient plant foods, insecticides, weed control techniques, or other technological innovations?

Table III. Projections of Alternative Farm Output and Factor Input Indexes for 1975

(1950 = 100)

	Zero technical progress		*Slow technical progress*		*Rapid technical progress*		*Very rapid technical progress*	
	Low land inputs (A)	*High land inputs (B)*	*Low land inputs (C)*	*High land inputs (D)*	*Low land inputs (E)*	*High land inputs (F)*	*Low land inputs (G)*	*High land inputs (H)*
1975 Projections								
Inputs:								
Labor	81	81	81	81	67	67	67	67
Land	90	110	90	110	90	110	90	110
Capital	378	348	218	185	238	219	144	133
Current operating expenses	491	441	285	234	311	277	189	173
Contributions to output from:								
Inputs	160	160	135	135	129	129	100	100
Technological change	0	0	25	25	31	31	60	60
Total output	160	160	160	160	160	160	160	160

SOURCE: Ruttan, V. W., *The Review of Economics and Statistics*, vol. XXXVIII, no. 1, February 1956, p. 65.

Within this over-all comparison, the projection of current operating expenses is likely to be of greatest interest to readers of AGRICULTURAL AND FOOD CHEMISTRY. Current operating expenses, which include such items as fertilizer, insecticides, processed feeds and feed additives, seed, tractor fuel, and equipment repairs, are expected to expand more rapidly than other input categories. Consumption of all items in this general category cannot be expected to expand at the same rate, of course. Some items among today's current operating expenses will disappear altogether. And many items that do not now appear can be expected to be added as a result of continued research and development. Consumption of fertilizer, one of the more important items in the current operating expenses category, is expected to expand at a very rapid rate, although somewhat less rapidly than the average of all current input items (Table IV).

Consumption of commercially prepared feeds is expected to continue to expand rapidly both as a result of increases in feed efficiency made possible by the newer feed additives, and as a result of further expansion of integration in the livestock industry. Use of pesticides can also be expected to expand more rapidly than the average. Farmstead mechanization, which has progressed much less rapidly than mechanization of field operations, and expansion of supplementary irrigation in the East can be expected to result in rapid increases in electric power consumption on the farm. Among the newer chemical products, such as plant stimulants, it is impossible to make a firm prediction. If the past is any guide, however, it seems certain that by 1975 farms will be purchasing from the farm chemicals industry substantial quantities of products which have not yet reached the laboratory stage—let alone dealers' warehouses.

Some Policy Implications

The projections of disposable income and population growth employed in this paper indicate substantially higher farm output requirements in 1975 than appeared likely even a few years ago. Regardless of the rate of technological change that is achieved, it appears that the output requirements can be met with approximately the same land inputs as at present and a continually declining agricultural labor force. The input-output models in this paper also illustrate the high degree of substitution that exists between technological change and inputs of capital and current expense items.

How Much Technological Change?

The changes in land inputs, nonland capital inputs, and the level of technology that actually take place will be strongly influenced by governmental policy. A major share of the costs of the research and development involved in advancing the level of technology in agriculture has traditionally been borne by the states and the federal government.

If, as argued in this paper, technological change and capital inputs can be viewed as substitutes, it then becomes possible to get away from the question of the quantity of resources (or income) which the nation "needs" to devote to research or to irrigation and reclamation if output requirements are to be met. A more appropriate question is: What combination of private and governmental expenditure on (a) research and extension, (b) irrigation and reclamation, and (c) investment incentives and expenditures will minimize the cost of obtaining the required increments to farm output?

No attempt will be made here to present a precise answer to this question. One would expect, however, that the situation represented by models A and B would be extremely costly. Cochrane and Lampe at the University of Minnesota have stated that they expect a situation similar to model G or H to hold during the next quarter century. Although this appears to be a substantially more rapid rate of change in output per unit of input than has been achieved for any period of similar length in the past, the possibility exists that this may be the least expensive method to the nation for providing its food and fiber requirements.

Land and Credit Policy

In the event that technological change is pushed rapidly enough to account for the entire increase in farm output (models G and H), problems of land reclamation and development and availability of farm credit are likely to become much less important than at present. Indeed, if the situation outlined in model G were to obtain, it would be possible to

Table IV. Plant Nutrient Consumption Projections for the U. S. and the East North Central Region

	United States		East North Central region	
	Amount (1000 tons)	Index	Amount (1000 tons)	Index
Actual consumption				
1950	4,058	66	790	54
1955	6,119	100	1,446	100
1956	6,055	99	1,426	100
1965 Projections				
High	7,700	126	2,100	145
Low	7,650	124	1,865	130
1975 Projections				
High	11,450	187	2,890	199
Low	10,050	165	2,500	173

SOURCES: Data for 1950-1957 are from Agricultural Research Service, U. S. Department of Agriculture, *Fertilizer Consumption in the United States* (Washington, D. C.), annual reports. Projections to 1965 and 1975 based on projection of past relationships between fertilizer input and the crop output component of total farm output.

achieve the desired farm output with a 10% decline in land inputs and only a 44% increase in nonland capital inputs over the 25-year period. This increase in capital inputs achieved during the 1940–1950 decade when nonland capital inputs in agriculture increased by approximately 65 per cent.

At the other extreme, failure to achieve substantial increases in output per unit of total input would point to continued rapid growth of capital requirements in agriculture, and would increase the productivity of both private and public investment in reclamation or drainage enterprises designed to increase land inputs. At the level of technological progress posited in models C and D, for example, an increase in land inputs of 20 points (from 90 to 110) permits a compensating decrease of approximately 33 units of capital and 51 units of current inputs between 1950 and 1975. At the levels posited in models G and H, the same increase in land inputs will release only about 11 units of capital and 16 units of current inputs.

The magnitude of the increase in capital inputs required in models A to F is of considerable interest. Some economists have expressed concern over the high capital requirements per farm unit even at present. Subtantial increases in total capital requirements coupled with further declines in the number of farms may make the ideal of an owner-operated family farm, unencumbered by substantial long-term debt, even harder to attain than at present. Certainly, such changes will require more effective arrangements for the acquisition of capital assets through long-term financing, and will probably be accompanied by separation of the farm ownership and managerial control functions to a much greater extent than exists at present.

Price Policy

In all of the farm output–factor input models shown in Table III, inputs of current expense items are indicated as expanding much more rapidly than long-run capital inputs. In the past increased expenditures on motor fuels have accounted for a major share of the increase in current inputs. It seems likely that rapidly expanding inputs of fertilizer, insecticides, machinery repairs, processed feeds, and other input factors purchased from the nonagricultural sectors of the economy will continue this trend.

As the importance of such items continues to expand, one might expect that farm output would become somewhat more sensitive to downward shifts in the prices of farm products than in the past. If this occurs, the old idea that farm output does not decline during a depression may have to be revised.

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