Technological Change and Resource Utilization in American Agriculture[1]

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1.0 Technological change in agriculture poses a major policy issue in almost every country of the world.

—In most countries the problem remains, as in the time of Malthus, how to relieve the "pressure of population on food supplies."

—In the U. S. the problem has been, for more than three decades, how to relieve the "pressure of food supplies on population."

The transformation between these two situations made possible by technological change is illustrated by the following item:

"Greek farmers grow enough wheat to meet home needs for the first time in history by using higher yielding varieties, more fertilizer, and switching to better tillage methods. Greece this year produced about 62 mllion bushels. Prior to World War II about half its requirements were imported, mostly from the U. S." (Wall Street Journal, October 10, 1961, p. 1).

The situation in Greece is not unique. The FAO continues to report additional countries in which the pressure of "population on food supplies" is being transformed into the pressure of "food supplies on population." Even the most densely populated areas of Western Europe are approaching self sufficiency in food production. (See "Trends in European Agriculture" FAO Monthly Bulletin of Agricultural Economics and Statistics," Vol. 9, #10, October 1960.)

2.0 Identification of the role of technological change in this transformation involves a number of difficult conceptual and emperical problems.

2.1 The conceptual problem:

2.11 Before technological change can occur certain prior events are necessary. The stage must be set by inventions or by scientific discoveries. Technological change does not occur until the new discoveries are utilized in production.

2.12 When technological change occurs its effects are felt in many ways. For purposes of economic analysis three aspects are particularly significant: (a) changes in production costs and/or the product mix of individual firms; (b) shifts in the demand for inputs used by firms and industries and shifts in the supply of products produced by firms and industries; (c) changes in the total level of resource utilization in relation to output in the economy as a whole. For the economy as a whole all cost reducing innovations become, through the operation of factor and product markets, output increasing innovations.

2.13 The significance of technological change for the growth of agricultural output, and for economic growth in general, is that it permits the substitution of knowledge for resources. Tradition-

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ally, we have thought of economic growth stemming from the substitution of resources (land, capital) for labor.

2.2 The measurement problem—how to separate the contribution of technology from the contribution of resources?

2.11 *Partial productivity* measures. $[O = T(W)]$
Such measures as output per unit of labor, land, breeding stock, or feed are useful but biased. Charges in these measures can occur as a result of changes in resource inputs as well as a result of changes in technology.

2.12 *Total productivity* approach. $[O = T\ (wW + lL + cC + eE)]$
The total productivity (output per unit of total input) or index number approach accounts for all inputs but does not take into account the fact that the rate of substitution between inputs and output, among inputs, and between inputs and technology varies with the amount used (fertilizer example).

2.13 *Production function approach.* $[O = T_A\ (W^w\ L^l\ C^c\ E^e)]$
A non-linear function such as the exponential permits wider latitude for substitution. Other functional forms are available. When estimated statistically the production function describes the new technology only as it exists on the average or typical farm in the group being studied.

2.14 *The diffusion function.* $[T_A = R\ (T_I)]$
In actual practice the technology used in the typical farm or the average technology for the nation as a whole will differ from the technology on the innovating farms depending on (a) the receptivity of the population to new ideas; (b) the efficiency of the communication or education system; (c) the size of the investment in obsolete equipment; (d) the rate of technological change itself; and others.

The best that can usually be done emperically is to measure T_A rather than T_I.

2.15 *The development level.* $\left[D = \frac{O}{P} = \frac{T_A\ (W^w\ L^l\ C^c\ E^e)}{P}\right]$
The per capita output of a society is a useful index to its level of economic development. If both sides of the production function equation are divided by the level of population the per capita output level (D) for the industry or economy being considered is obtained. The level of resource inputs necessary to achieve a particular level of per capita output depends on the relationship between the rate of technological change and the rate of population growth. If the rate of technological change can be pushed above the rate of population growth the level of per capita output can be increased with no increase in resource inputs.

3.0 The Output Explosion in American Agriculture.

This background on the conceptual and emperical issues relating to technological change should shed new insight on the output explosion in American agriculture that we have experienced over the last several decades.

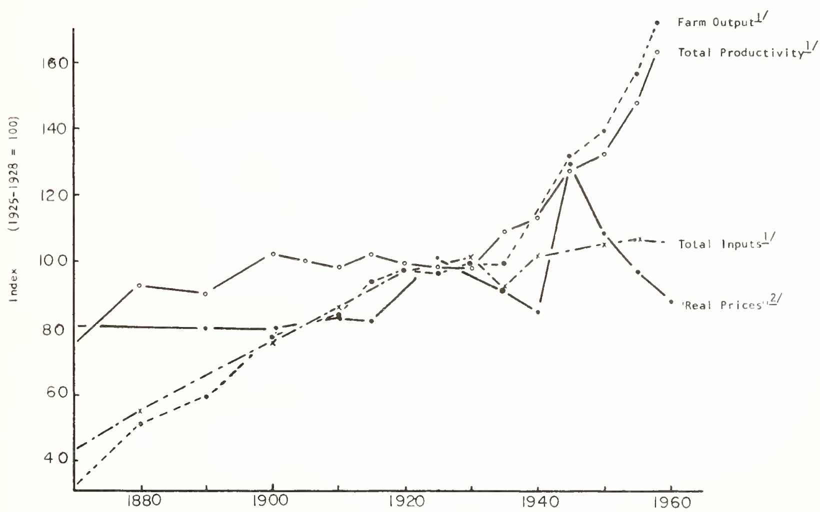
3.1 *Significance of output explosion in relation to discussion of early 1950's.*

The President's Water Resources Policy Commission (*Water Policy for the American People,* Vol. I, USPGO, Washington 1952, p. 156-1959) warned that equivalent of 100 million acres of cropland would have to be added to meet 1975 farm output requirements. It warned that approximately two-thirds of this increase would have to come from resource development activities such as irrigation, flood protection, drainage and land clearing if American farmers were to fill, in the Department of Agriculture's terminology, the "fifth plate" resulting from population growth. By 1960 the nation's farmers had already filled the "fifth plate" and were well on their way toward filling a sixth. The error of these and other projections of the early 1950's reflected failure to visualize technology as a substitute for resource inputs.

3.2 *The longer run picture.*

3.11 The last decade is in sharp contrast to longer run picture (See Figure 1 and Table 1).

Figure 1. Indexes of Output, Input, Productivity and Real Prices in Agriculture, 1870-1959



1/ USDA, "Changes in Farm Production and Efficiency", Stat. Bul. 233, July 1960, p. 48

2/ Barnett, Harold J. "Measurement of Natural Resource Scarcity and Its Economic Effects" National Bureau of Economic Research, October 1958, (Mimeographed).

Between 1870 and 1900 almost two-thirds of the increase in output was accounted for by increased inputs and one-third by technological change. Output rose by 3.7 percent per year while resource inputs expanded by 2.0 percent per year and total productivity by 1.1 percent per year. The supply of resources was sufficiently elastic, when combined with the flow of new technology, to permit an extremely rapid rate of increase in farm output with no increase in "real" farm prices.

Table 1. Annual Average Rates of Change in Total Output, Inputs and Productivity in American Agriculture, 1870-1958.[1]

Changes of	1870-1900	1900-25	1925-50	1950-58
	(percent per year)			
Gross Output	3.2	0.9	1.5	2.5
Gross Inputs	2.0	1.0	0.4	0.0
Gross output per unit of gross input	1.1	–0.0	1.2	2.5

1. USDA, "Changes in Farm Production and Efficiency," Stat. Bul. 233, July, 1960, p. 48.

2. Harold J. Barnett, "Measurement of Natural Resource Scarcity and Its Economic Effects," National Bureau of Economic Research, October, 1958 (mimeographed).

Between 1900 and 1925 a slow rate of growth in resource inputs combined with failure to achieve any measurable increase in total productivity reduced the rate of growth of farm output to less than 1%. This was the only period since 1870 which experienced a sustained increase in agricultural prices relative to the general price level. With the application of new technology proceeding only fast enough to offset the effect of diminishing returns even relatively rapid price increases were not sufficient to draw additional resources into agricultural production fast enough to maintain a rate of growth in agricultural output equal to the rate of population growth.

Since the mid 1920's the rate of technological change has risen at an increasing rate. Between 1925 and 1950 a 1.2 percent annual change in total productivity and a 0.4 percent annual increase in resource utilization combined to produce an output expansion of 1.5 percent per year. By the 1950 decade total productivity was increasing at a sufficiently rapid rate to account for the entire increase in farm output.

3.12 Significance of 1910-1925 for development of (a) conservation and (b) research and extension policies.

The implications of lagging productivity and diminishing returns to resources during the first quarter of this century were brought to the attention of consumers and legislators through the mechanism of rising food prices. The public concern with resource policy generated during this period expressed itself in terms of both (a) increased emphasis on conservation and development of physical resources and (b) in increased allocation of public funds for research and education designed to speed the rate of technological change in American Agriculture.

The success of these policies is further evidence that it is possible to regard technological change and resource investment as partial substitutes for each other in achieving agricultural development. The problem of agricultural development can now be stated in terms of achieving the most efficient combination of expenditures on resource conservation and research and education leading to technological change rather than simply assuring that the nation and the world will be able to meet expanding food and fiber requirements.

4.0 Implications of technological change for future resource requirements in American Agriculture.

4.1 Impact of alternative rates of technological change on use of input factors (Table 2).

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 *projections* for the mid-1970's. It is 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 basic technological change possibilities are identified in Table 2. 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 2), 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 decline capital and current input requirements.

Table 2. Projections of Alternative Farm Output and Factor Input Indexes for 1960 and 1975 (1950 = 100).

		Zero technical progress[a]		Slow technical progress[b]		Rapid technical progress[c]		Very rapid technical progress[d]	
		Low land inputs (I)	High land inputs (II)	Low land inputs (III)	High land inputs (IV)	Low land inputs (V)	High land inputs (VI)	Low land inputs (VII)	High land inputs (VIII)
1960 Projections									
Inputs:									
Labor		88	88	88	88	78	78	78	78
Land		96	104	96	104	96	104	96	104
Capital[e]	(A)	178	172	140	136	149	143	124	121
	(B)	183	177	145	140	153	147	127	124
Current[e]	(A)	214	207	169	163	178	172	148	145
	(B)	204	198	161	155	171	164	141	138
Contribution to output from:									
Inputs		122	122	112	112	110	110	100	100
Technological change		0	0	10	10	12	12	22	22
Total output		122	122	122	122	122	122	122	122
1975 Projections									
Inputs:									
Labor		81	81	81	81	67	67	67	67
Land		90	110	90	110	90	110	90	110
Capital[e]	(A)	346	318	199	169	218	201	132	122
	(B)	378	348	218	185	238	219	144	133
Current[e]	(A)	547	505	317	240	346	318	210	193
	(B)	491	441	285	234	311	277	189	173
Contribution 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

a. Increased inputs are assumed to account for the entire increase in output.

b. Technological change is assumed to occur at a sufficiently rapid rate to permit an increase in output per unit of input of 1.0 per cent per year between 1950 and 1975. This is the 1910-50 rate calculated on the basis of 1945-48 prices and techniques.

c. Technological change is assumed to occur at a sufficiently rapid rate to permit an increase in output per unit of input of 1.23 per cent per year between 1950 and 1975. This is the 1910-50 rate calculated on the basis of 1910-14 prices and techniques.

d. It is assumed that technological change occurs at a sufficiently rapid rate to account for the entire increase in output. This requires an increase in output per unit of input of 2.2 per cent per year between 1950 and 1960 and 2.4 per cent per year between 1950 and 1975.

e. Estimate (A) for capital and current inputs is based on the assumption that the ratio of capital to current inputs (C_1/C_2) will continue to decline at the same percentage rate as during the period 1910-14 to 1945-48.

Estimate (B) is based on the assumption that the 1925-27 to 1949-50 rate will continue. See text for further discussion of estimates A and B.

Source: V. W. Ruttan, "The Contribution of Technological Change to Farm Output: 1950-75," *Review of Economics and Statistics*, Vol. 38, No. 1, February, 1956, p. 65.

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. 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.

Table 3. Indexes of Farm Output and Input Changes 1950-59 and Projections to 1960 and 1975.

	Actual 1959[1]	1954 Projections[2]		Revised Projections[3]
		1960	1975	
Output—% of 1950 output	126	122	160	160–65
Labor	66	78	67	45–50
Land	96[a]	96–104	90–110	90–110
Non-Land Capital				
(includes buildings	119	121–27	122–44	130–35
Operating Expenses	139	138–48	173–210	170–200

a. The 1959 index is based on acreage of harvested crops only. The projections are in terms of a weighted quantity index in which irrigated cropland, non-irrigated cropland and pasture are given separate weights based on productivity and market price criteria. The decline in acreage harvested since 1950 has been at least in part offset by increases in irrigated acreage.

Source: (1) Computed from U. S. Department of Agriculture, Changes in Farm Production and Efficiency, Statistical Bulletin 233, Washington, July 1960.

(2) V. W. Ruttan, "The Contribution of Technological Progress to Farm Output: 1950-75," *Review of Economics and Statistics*, Vol. 38, No. 1, February 1956, pp. 61-64 (Models VII and VIII).

(3) Revisions of data presented in V. W. Ruttan, *Ibid.*

4.2 Where are we heading by 1975 (Table 3)?

The projections presented in Table 2 (constructed in 1954) appear to underestimate the rate at which capital inputs were substituted for labor inputs during the decade of the 1950's. Overall patterns appear, however, to conform rather closely with that of Models VII and VIII. In Table 3 the projections are compared with the actual experience of the last decade and revised projections which takes this experience into account are presented. It would appear, with total productivity rising at close to 2.5 percent per year and population expanding at 1.8 percent per year the American Economy will continue to experience "pressure of food supplies on population."

5.0 *Question*—What does a rate of technological change which exceeds the rate of population growth imply for research workers, farmers and consumers?

The record of the past several decades indicates that research workers in agriculture have been particularly successful in developing new knowledge leading to the substitution of technology for resources inputs in agricultural production. Farmers have attempted, through agricultural programs, to capture a significant share of these gains. In this attempt they have been only partially successful. The declining agricultural prices during the last decade indicates that a substantial share of the gains from new technology are being passed on to consumers.

In the future consumers will be best served by a continuation of a national policy which encourages the support of agricultural research, development and education. The rising food costs that could result from failure to maintain a rate of technological change that at least approximates the rate of population growth could easily exceed the costs of agricultural research and education. A rate of technological change in agriculture which exceeds the rate of growth in demand will, on the other hand, create political pressures on the part of farmers for protection against the loss of asset values and income stemming from declining farm prices.