Technological Change in Agriculture

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AMERICAN AGRICULTURE has become one of the most productive industries in the world. The tremendous growth of its productivity may be attributed in part to the great advances made in agricultural technology. This paper attempts to quantify in index form the rate at which technology has changed in agriculture from 1950 to 1966. In addition an analysis is made of the role of farm machinery in increasing agriculture's output.

Many authors have attempted to measure changes in the production function using various modifications of the Cobb-Douglas model. Their analysis, however, is limited to a specific time period. Any attempt to measure the contribution of the productive factors over time will be faced with the familiar problem of multicollinearity. Attempts to determine the role of each factor are then limited by the accuracy of the regression coefficients.

This paper employs the basic mathematical approach developed by Robert M. Solow (9)[2] with some modifications for its application to agriculture. This method eliminates some of the problems mentioned above but is still limited by the assumptions which must be made.

The Model

Technological change can be broadly defined as a change in the total farm output that results from a given set of production inputs. These changes will cause both neutral shifts and changes in the slope of the production function. Solow's method measures technological change as a residual of the output per unit of labor minus the capital inputs per unit of labor. Therefore improvements in education, management techniques, quality of the production inputs, and all the other things that result in an increase in farm output will appear as "technological change."

To measure technological change, the variations in output due to movements along the production curve must be separated from those that are due to shifts in the curve. This can be accomplished by making three basic assumptions: (1) each factor is paid its marginal product, (2) the production function is homogeneous to the degree one, and (3) there is neutral technological change.

The first assumption is the usual assumption for an economy in an equilibrium condition. The second assumption states that there are constant returns to scale to the factors employed. There are some indications that the limitations imposed by the first two assumptions are not overly restrictive. Agriculture has not shown any substantial bias resulting from violation of the equilibrium condition and production economic research has shown some evidence that agriculture is characterized by approximately constant returns to scale (10).

Technological change is not always neutral in agriculture but this assumption is made to simplify the analysis. Neutral technological change occurs when the production function shifts either up or down and the productivity coefficients remain unchanged. Solow attempts to test for neutrality of technological growth but the results are rather inconclusive.

Although these assumptions are rather restrictive, they are probably as tenable in describing agriculture's production function as they would be in describing any other industry. Any interpretations or conclusions drawn from this study must be made in light of these assumptions.

The production function is described as a functional relationship of all the inputs used in production to the final output. The inputs are usually characterized by the physical units of labor and capital. The production function can be written:

$$Q = f\ (K, L,\ ;\ t) \qquad (1)$$

Q represents the total output, K and L represent physical units of capital and labor used in production. The variable t is a time variable that is used to measure the technological change that occurs. Solow describes t

[1] The author is indebted to Hazen F. Gale of the Bureau of Labor Statistics for his many useful comments and criticisms.

[2] Underscored numbers in parentheses refer to the Literature Cited, p. 18.

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"as a shorthand expression for any kind of shift in the production function" (9).

Based on the assumption that technological change is neutral, we can rewrite equation (1) as:

$$(2) \qquad Q = A(t)\ L^{1-B}\ K^{B}$$

The multiplicative factor A(t) changes over time and causes the output to change for any given set of factor inputs. Since we have also assumed constant returns scale, the exponents will add to unity. This makes it very convenient to express the production function in terms of output per man-hour or capital per man-hour. The equation would take the form:

$$(3) \qquad Q/L = A(t)\left(\frac{K}{L}\right)^{B}$$

Equation (3) can be written as a log function and used to describe a time series or a change from period to period by the form

$$(4) \qquad \Delta\log\ (Q/L) = \Delta \log A(t) + B\Delta\log\ (K/L)$$

where Δ signifies the differences in values between two adjacent periods. The differences in logarithms can be expressed as a percentage of change in the original variables. Therefore, we can write:

$$(5) \qquad \frac{\Delta\,(Q/L)}{Q/L} = \frac{\Delta\, A(t)}{A(t)} + B\,\frac{\Delta(K/L)}{K/L}$$

From equilibrium theory we know that $B = \frac{I \cdot K}{P \cdot Q}$ where P is the price of the output (Q) and I is the cost of capital (K). If we represent $Q/L = q$, $K/L = k$, $B = W_k$ which is capital's share of output, and $\Delta A/A$ as the percentage change in the production function, then equation (5) can be written:

$$(6) \qquad \Delta A/A = \Delta q/q - Wk\ \Delta k/k$$

The change in output caused by the total changes in the use of capital per unit of labor is subtracted from the total change in output. The residual $\Delta A/A$ is then the change in production that was caused by some neutral change in technology.

Solow's method must be modified somewhat to describe agriculture's production function. The capital used in agriculture's production has been placed into three separate categories. The first category includes land, buildings, livestock, and other inventories; the second includes farm machinery and equipment; and the last includes the intermediate purchased products used in production for a single year only, i.e., feed, fertilizer, seed, etc.

Solow's original equation–equation (6) in this paper–is therefore rewritten to include both farm machinery and the intermediate purchased products:

$$(7) \qquad \Delta A/A = \Delta q/q - WM\ \Delta m/m - WI\ \Delta i/i - WK\ \Delta k/k$$

where m is the inputs of farm machinery per unit of labor, WM is machinery's share of the output per unit of labor, i is the intermediate products used per unit of labor, WI is the intermediate purchased inputs share of output per unit of labor, k is the capital input in the form of land, buildings, and inventories per unit of labor, and WK is k's share of output per unit of labor.

The terms of the equation, $\Delta q/q$, $\Delta k/k$, $\Delta m/m$, and $\Delta i/i$, are correct only for infinitesimal changes. If there are large changes, q, k, m, and i would be incorrect divisors and would introduce a bias into the technological index. To minimize this bias, values of q, k, m, and i are taken to be an average value between two adjacent 3-year averages (2). The final equation which is used in this study can be written:

$$(8) \qquad \frac{\Delta A}{A} = \frac{\Delta q}{\frac{q_{t_1} + q_{t_2}}{2}} - WK\,\frac{\Delta k}{\frac{k_{t_1} + k_{t_2}}{2}} - WM\,\frac{\Delta m}{\frac{m_{t_1} + m_{t_2}}{2}} - WI\,\frac{\Delta i}{\frac{i_{t_1} + i_{t_2}}{2}}$$

The output and the inputs in equation (8) are expressed in constant dollar units. $\Delta A/A$, which is the expression for technological change in agriculture, can now be derived as a residual by subtracting the change in the inputs from the change in output.

The index of technological change was computed by setting the first period A(t) 1950 = 1 and then using the equation

$$A(t+1) = A(t)\left(1 + \frac{\Delta A(t)}{A}\right)$$

to construct a value for the remaining periods. This will give a separate measure of technological change for each period in the study.

Nature of the Data

All the data used in this paper are obtained from USDA sources (10). The data were adjusted to constant 1957-59 dollars by deflating the output and each input separately by an appropriate price index (1957-59 = 100). Because of the sharp fluctuations in the data, a 3-year moving average was used to smooth out the major irregularities due to weather and other extraneous factors.

The gross value of all crops and animals raised on the farm was used as a measure of agriculture's output. This includes both the products sold off the farm and those which were used on the farm. All the values in this study are expressed in terms of either gross value of output per unit of labor or gross capital per unit of labor. When using gross terms in a Solow-type model, we must consider depreciation as a part of the factor shares.

Labor inputs are expressed in total man-hours worked. This includes all the man-hours worked by the farm operator, his family, and hired workers.

The data have been arranged in 15 time periods covering the years from 1950 to 1966. Each period represents a 3-year moving average of both the gross farm output per unit of labor and the capital per unit of labor. Since the mathematical method used in this analysis calls for each factor to be paid its marginal product, we must assume that a perfectly competitive equilibrium exists for each period. It is generally considered that agriculture is not in a state of equilibrium for any year but the use of the 3-year moving average would tend to approximate this condition. The number of years used in the moving average was only limited by the fact that each additional year decreased by one the already small number of degrees of freedom.

The capital input "K" was defined to include land, buildings, and inventories of livestock and crops on the farm as of January 1 of each year. An annual charge of 5.0 percent for this type of capital input was used to compute its share of the gross farm output. This rate was the average interest rate charged by the Federal land banks during the time covered in the analysis.

The inputs in the farm machinery sector include 40 percent of the autos on the farm, 78 percent of the trucks, and the entire stock of tractors and all other types of farm machinery. An annual charge of 6.4 percent for machinery was used to compute its share of gross farm output. This percentage was the average interest rate charged by the Farm Production Credit Association during the time covered in this analysis.

The use of the interest rate to determine each input's factor share may not be realistic, but it is consistent with the assumptions of the Solow type model. If we assume a state of equilibrium for every time period, each unit of capital should be earning a rate of return equal to the interest rate charged. In many studies of this type a rate of interest of 6 to 8 percent is used to compute farm machinery's factor share. In this context, my interest charge of 6.4 percent is not entirely out of line. The interest rates used in my study also show the differential between the interest rates charged on land and buildings and the interest charged on machinery and equipment for the time period covered in this analysis.

The value of purchased intermediate capital inputs "I" was the sum total of the operating expenses incurred for each period covered in the analysis. The intermediate capital inputs include feed, seed, fertilizer, building and machinery repairs, taxes, and other miscellaneous expenses.

Results

The index of agriculture's technological change shows that A(t) has increased about 87 percent over the 15 time periods (table 1). The average rate of technological growth over the 15 periods is about 4.6 percent. At the same time, table 1 also shows that the output per man-hour has more than doubled.

A plot of the movements of A(t) over time shows that technology has increased in all years except for a slight decrease in 1961-63. The constant increase can be partly attributed to the effects of use of the moving average in the data series.

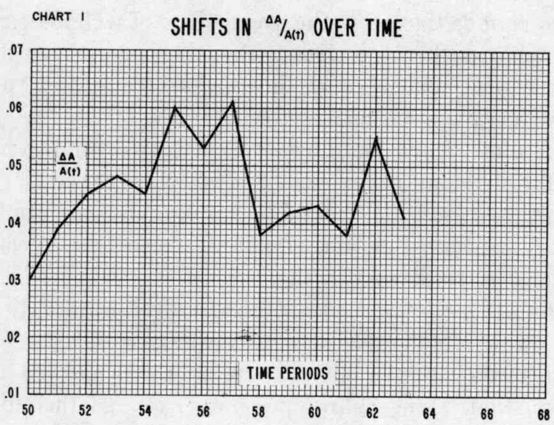
Chart 1 shows a plot of $\Delta A/A$ over the 15 time periods covered in the analysis. A regression of the $\Delta A/A$ against the sum of all the capital inputs showed no correlation. Using Solow's reasoning, we can therefore assume that from 1950 to 1966 shifts in the aggregate production function "netted out" to be approximately neutral (9). Solow describes neutrality to mean the shifts in the production that change output but leave the marginal rate of substitution between the factors unchanged at some given capital to labor ratio.

Murray Brown states that the method used by Solow to test for neutrality is not conclusive in itself because the capital-labor ratio could change in such a way as to leave the proportional changes in the function zero and still there might be a nonneutral change (1). Griliches, however, indicates that there is no reason to dispute the finding that agriculture does have neutral technological growth (3).

By using Solow's approach, it is possible to show that over the 15 time periods used in my analysis, one-fifth

Table 1.–Index of technological change in agriculture and the components of the index, 1950 to 1966

Period	Output per unit of labor (q)	Capital per unit of labor (k)	Machinery per unit of labor (m)	Intermediate products per unit of labor (i)	Capital share (K)	Machinery share (M)	Intermediate share (I)	Change in production function Δ A/A	Techno-logical change index A(t)
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Ratio*	*Ratio*	*Ratio*		
1950 - 52	1.733	8.965	0.993	0.774	0.258	0.0366	0.0453	0.0304	1.000
1951 - 53	1.824	9.487	1.098	.814	.260	.0385	.0446	.0394	1.0304
1952 - 54	1.936	10.032	1.213	.858	.259	.0400	.0443	.0452	1.0709
1953 - 55	2.047	10.259	1.303	.907	.251	.0416	.0443	.0484	1.1193
1954 - 56	2.178	10.586	1.398	.976	.243	.0411	.0448	.0449	1.1734
1955 - 57	2.325	11.224	1.488	1.063	.241	.0409	.0457	.0603	1.2260
1956 - 58	2.531	12.097	1.573	1.173	.239	.0397	.0464	.0538	1.2999
1957 - 59	2.731	12.937	1.643	1.286	.237	.0385	.0474	.0611	1.3698
1958 - 60	2.952	13.604	1.707	1.394	.230	.0370	.0472	.0382	1.4534
1959 - 61	3.111	14.217	1.768	1.487	.228	.0363	.0478	.0425	1.5089
1960 - 62	3.290	14.744	1.859	1.601	.224	.0361	.0487	.0429	1.5730
1961 - 63	3.474	15.248	1.902	1.720	.219	.0350	.0495	.0381	1.6404
1962 - 64	3.658	15.866	1.982	1.841	.217	.0346	.0503	.0550	1.7028
1963 - 65	3.908	16.479	2.066	1.963	.211	.0338	.0502	.0414	1.7964
1964 - 66	4.141	17.301	2.235	2.113	.209	.0345	.0510	–	1.8708



of agriculture's increase in output can be attributed to the use of total capital per man-hour and four-fifths to technological change. To compute the contribution of capital divide the 1964-66 value of output per man-hour (4.141) by 1.8708 which is the 1964-66 index of technological change (value for A(t)). This will produce a value of output per man-hour that is net of all technological change resulting from shifts in agriculture's production function over the 15 time periods. This new or "corrected" value (2.213) minus the 1950-52 output per man-hour of 1.733 determines a measure of capital contribution toward the increase output. Therefore, about 48 cents of the $2.41 increase can be attributed to increased capital intensity and the remainder to increased productivity.

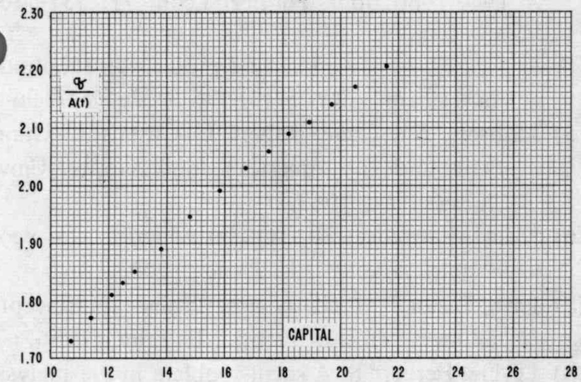
This means that approximately 80 percent of the increase in output per man-hour can be attributed to technological change and 20 percent to the increase in capital intensity.

If we had started with factor technology and had credited the remainder to capital intensity, we would find that 37.3 percent (rather than 20.0 percent) of the increase in output per man-hour could be imputed to increased capital intensity. The percentage increase in output per man-hour is 138.9 percent and the increase in technology A(t) is 87.1 percent. Thus, technology accounts for 87.1/138.9 or 62.7 percent and the remainder or 37.3 percent is credited to capital intensity (8).

If we combine the two methods described above, we can say that between 62 and 80 percent of the increase in output per man-hour can be attributed to technical change and between 20.0 and 37 percent can be attributed to capital intensity.

A plot of the output per man-hour corrected for any change in technology (Q/A(t)) against the total capital used shows that there is a close relationship (chart 2). Chart 2 gives the visual impression that the graph is slightly downward sloping. By fitting various types of regression equations to the data it was shown that a curvilinear function had a slightly higher coefficient of determination than the linear function. This would seem

CHART 2 A SCATTER OF Q/A(t) AGAINST CAPITAL



to indicate that agriculture's aggregate production function does show a tendency toward diminishing returns.

It is of interest to note that when the Cobb-Douglas function was applied to the aggregate production function for agriculture, the B value for total capital was 0.351. This seems to be consistent with both Douglas's and Solow's findings that capital contributes about one-third to the total output.

Farm Machinery Analysis

It was shown above that 48 cents or 20 percent of the increase in the output per man-hour could be attributed to the increased use of total capital. Using the usual assumptions made for the Cobb-Douglas function, we can say that each factor contribution toward its output is proportional to its beta coefficient. The b value for farm machinery during the periods covered in the analysis was found to be 0.03319. From this value we are able to compute the contribution made by farm machinery as a percentage of the increase attributable to the use of total capital. Of the 48 cents attributed to total capital, farm machinery contributed about 9.4 percent or about 4½ cents.

Table 1 shows that the factor share of farm machinery (W_M) has shown a definite decline for the periods 1955-57 to 1963-65 while the farm machinery per unit of labor (m) has continued to increase. There seems to be a slight increase in farm machinery's factor share in 1964-66.

In an effort to determine the direct effects that farm machinery has played in the agricultural technology change, I recomputed the index of technology excluding the farm machinery input. This had the effect of lumping the increase in output directly attributed to farm machinery with the new index of technology $A(t)'$. The recomputed index showed an $A(t)'$ value of 1.9269 for the last period. Therefore, the extra output, which can be directly attributed to the use of farm machinery, increased the index by only 0.0561 index point.

A semilog graph of the output per man-hour corrected for technological change ($Q/A(t)' - Q/A(t)'$) plotted against the inputs of farm machinery used in each period showed a downward sloping curve. The chart indicates that the output due to farm machinery is increasing but at a decreasing rate. These results indicate that farm machinery is reaching a point of saturation, but the data presented here do not show this conclusively.

The data seem to indicate that farm machinery has not had an appreciable direct impact on agriculture's increase output. Since technology in this paper is measured as a residual of the output produced and inputs used in production, farm machinery's contribution to the agricultural index of technology would be very slight. G. Johnson and R. Gustafson studied the effects of farm machinery's role in increasing farm output and obtained results similar to my findings (5). They found that the increase in farm mechanization just offset the decrease in the labor input and that machinery's contribution toward output netted out to be either a very slight increase or decrease, depending on how the "interaction" effects between the inputs were allocated.

Throughout this paper I refer to only slight direct effects that farm machinery has contributed toward farm output and technological change. Farm machinery, however, when used in combination with other inputs, does help to increase output, but these so-called interaction effects are impossible to measure accurately. The Cobb-Douglas function as used here expresses the inputs in logs which are then additive. This has the effect of expressing the input variables independently of the level of application. The results would then only show the direct effects of the use of the measured variable, and would not show the effects of using the variables in combinations or the interaction effects.

Summary

1. Agriculture's index of technology increased about 87 percent from 1950-52 to 1964-66. This indicates that technology has had an average annual growth rate of about 4.6 percent.

2. Gross output per man-hour more than doubled, with between 62 and 80 percent of increase attributed

to technical change and between 20 and 38 percent to increased capital intensity.

3. Capital has accounted for approximately 35 percent of the total output. This finding is consistent with the findings of Douglas and Solow in their studies in the nonagricultural sectors of our country.

4. Agriculture's aggregate production function, corrected for technological change, shows a tendency toward diminishing returns. This tendency, however, seems to be very slight.

5. Farm machinery seems to play only a minor *direct* role in agriculture's increased output.

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