TECHNOLOGICAL CHANGE AND THE RELATIVE SHARE OF LABOR: THE CASE OF TOBACCO PRODUCTION IN THE U.S.

Pradeep Ganguly

Tobacco production traditionally has been a highly labor-intensive operation in this country. Although the entire crop is grown on only .3 of 1 percent of the total cropland, tobacco requires more labor than is required for all vegetable crops and about the same amount as needed for cotton and food grains combined (USDA, *Agricultural Statistics*). However, in recent years a growing trend toward mechanization of harvesting-curing operations has, among other effects, greatly reduced labor usage. During the time period 1949-1976, total man-hours in tobacco production in the United States declined from 747 million to only 275 million—a reduction of more than 63 percent (USDA, *Agricultural Statistics*). Much of this reduction has been due to the introduction of bulk curing barns and mechanical harvesters (multipass and once-over types), which have replaced tying by hand or machines, conventional barns, and walking or riding primers. Mechanization of tobacco production has been relatively slow because of the special growing, harvesting, and curing requirements. However, the present state of mechanization is not insignificant.

Studies by Ferguson and Moroney, Kravis, and Solow indicate that in relation to other inputs the share of labor in U.S. manufacturing increased during the postwar period. This increase can be explained by the fact that in most high technology industries, substitution of capital for labor is becoming increasingly difficult and thus the elasticity of substitution is low. U.S. agriculture, in contrast, has yet to reach that point; in fact, in certain areas, mechanization has been rather slow. The relative ease of substitution of capital for labor, coupled with a labor-saving technological change, has reduced the relative share of labor in U.S. agriculture. Thus, an increase in the relative share of labor may be a "stylized fact of modern capitalism," at least for the time being, only for the manufacturing sector.

Ruttan and Stout point out that the relative share of labor in U.S. agriculture declined during the period 1944-1957 after remaining relatively constant in the prewar period. Lianos made three estimates of labor's relative share in U.S. agriculture for the period 1949-1968 which clearly indicate this declining trend. The trend can be seen more clearly in those sectors of agriculture which have traditionally been highly labor intensive. A study of U.S. cotton production by Martin and Havlicek shows that the relative share of labor declined from 39 percent to 22 percent during the period 1952-1969. Using a CES production function, they estimated that the elasticity of substitution in U.S. cotton production was 1.5. A similar approach is used in this study. Additional estimates of the elasticity of substitution parameter are obtained. Also, the theoretical models of Ferguson and Maroney and of Lianos form the basis for estimating the bias of technological change in tobacco production.

Substitution of capital for labor in tobacco production has been induced by increasing labor costs, the uncertainty and difficulty of obtaining harvest labor (due partly to the demise of the sharecropper), the availability of credit and machinery, and the profitability of expanding the size of operations (facilitated somewhat by intracounty transferability of marketing quota). The above-mentioned factors can be expected to lead to additional capital-labor substitution and a further decline in labor's relative share in tobacco production in the 1980s.

The objectives of this article are (1) to estimate the changes in labor's relative share in U.S. tobacco production for the period 1949-1976, (2) to estimate the elasticity of factor substitution, (3) to estimate the bias of technological change, and (4) to compare these findings with those of similar studies.

BASIC ASSUMPTIONS

Assume an aggregate production function with marginal product of each factor diminishing monotonically. Specifically, let the production function be given by

Pradeep Ganguly is Assistant Professor, Department of Economics, University of South Carolina at Aiken.

The author is indebted to anonymous reviewers of the *Journal* for their helpful comments and suggestions. The research for the article was done while the author was a Ph.D. student in the Department of Agricultural Economics, Clemson University.

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

where f is homogeneous of the first degree in the factors of production, capital (K) and labor (L), $f_K > 0$, $f_L > 0$, $f_{KK} < 0$, $f_{LL} < 0$. Time is introduced in the function to allow for technological change.

The production function for tobacco needs to take into consideration acreage-poundage allotments over time.[1] Because the purpose of such allotments has been to limit production, the tobacco production function is essentially an output-constant production function. During the time period 1949-1976, the annual output of tobacco averaged about 2 billion pounds, with relatively small variations due to acreage and poundage (marketing) quota adjustments (Ganguly and Thompson). As total area under tobacco has been relatively constant,[2] the production function allows for primarily capital-labor substitution over time. Symbolically, the industry production function can be expressed as

$$(2) \qquad \overline{Y} = g(K,L,t|\overline{A}),$$

where $\overline{Y}$ is the output-constant production function and $\overline{A}$ is the tobacco allotment. The tobacco producers are faced with the problem of minimizing total production costs subject to the constraint of a constant output. Specifically, the problem is

$$(3) \qquad \text{minimize } C = r\cdot K + w\cdot L + a\cdot\overline{A} + \overline{c}$$

$$\text{subject to } g(K,L|\overline{A}) = y,$$

where r and w are the prices of capital and labor, respectively, a is the rental rate for marketing quota (which is equal to zero if quota is owned rather than rented) and may be considered a fixed cost per pound of tobacco, y is the firm's production function, and $\overline{c}$ is a fixed cost component. The tobacco producer can then be shown to minimize total cost of producing a given output (i.e., maximize net returns) where the marginal rate of technical substitution between capital and labor is equal to the factor price ratio. This rental rate does not, however, affect the marginal considerations for cost minimization; from the individual producer's standpoint, it makes output an additional variable with a fixed additional cost per pound. For the tobacco-production sector as a whole, the intraindustry transfers cancel out and the implications of equation 2 are not affected.

Assume further that the rewards to labor and capital are equal to the value of their respective marginal products ($w = f_L$, $r = f_K$). Thus pure competition is implicitly assumed in both the product and factor markets. One can safely assume competitive pricing in the factor markets where there are large numbers of buyers and sellers of similar services. The tobacco product market, however, is characterized by oligopsony—a large number of competitive sellers against a few large buyers on the auction floors. This situation calls for certain adjustments in the product market, with indirect effects on the factor markets. The tobacco marketing system does safeguard the interests of all producers, even though the small producer is like "an ant against an elephant" (Mann).

RELATIVE SHARE OF LABOR

Relative share of labor in tobacco production is defined as

$$(4) \qquad S_L = \frac{w\cdot L}{Y}$$

where

w= real wage rate
L = man-hours
Y = real value of output.

Because tobacco farmers buy inputs from nonfarm businesses, there is some overestimation of Y and, consequently, an underestimation of labor's relative share.[3] In spite of this problem, relationship 4 can be assumed to bring out the trend in the relative share of labor.

The relative share of labor depends on two parameters—the bias of technological progress, B, and the elasticity of substitution, σ (which also incorporates the capital-labor ratio). Following Hicks, we can define the bias of technological change as the proportional change in the ratio of marginal products of capital and labor (Ferguson). Symbolically,

$$(5) \qquad B = \left[\frac{\partial\left(\frac{f_K}{f_L}\right)}{\partial t}\right] \div \left(\frac{f_K}{f_L}\right).$$

[1]Acreage and/or poundage allotments are in effect in tobacco production with few minor exceptions. In the case of Maryland tobacco (type 32), no production quotas are in effect. For Connecticut Valley tobacco (type 52), production quotas were recently suspended as not enough of type 52 was being produced. (The author is indebted to Max I. Lloyd of Clemson University for this information.) Note, however, that together Maryland and Connecticut Valley tobacco constitute only about 1 percent of total U.S. tobacco output.

[2]The total area under tobacco has fluctuated around 1 million acres (USDA, *Agricultural Statistics*).

[3]This point is made by Lianos.

Taking the derivative of f_K and f_L with respect to time and rearranging, we have

$$(6) \quad B = \left(\frac{\partial f_K}{\partial t} \div f_K\right) - \left(\frac{\partial f_L}{\partial t} \div f_L\right).$$

If both f_K and f_L (the marginal physical products of capital and labor, respectively) increase at the same rate over time, technological change is said to be neutral. If the rate of increase of f_K over time is greater than that of f_L, technological change is labor-saving (capital-using) and vice-versa. In other words, technological change is Hicks neutral if $B = 0$, Hicks labor-saving (capital-using) if $B > 0$, and Hicks labor-using (capital-saving) if $B < 0$.

The elasticity of factor substitution (σ) is symmetrical with respect to the factors of production for movements along an isoproduct curve. Assuming a constant-return-to-scale production function and using Euler's theorem, we can express the elasticity of substitution as (Allen, p. 343)

$$(7) \quad \sigma = \frac{f_K f_L}{Y f_{KL}}.$$

It is well known that the rate of change of labor's relative share depends on the parameters σ and B. In the extreme cases where $\sigma = 1$ (as in a linearly homogeneous production function) or $B = 0$ (neutral technological progress), the relative share of labor remains constant (irrespective of the value of the other parameter). If $\sigma > 1$ and $B > 0$ or if $\sigma < 1$ and $B < 0$, labor's relative share will tend to decrease despite an increase in wage rates. Labor's relative share will increase if $\sigma < 1$ and $B > 0$ or if $\sigma > 1$ and $B < 0$. Ferguson and Moroney and also Lianos provide a detailed discussion and derivation of these relationships. In U.S. manufacturing the latter of the two situations seems to have developed, resulting in an increase in labor's relative share.

Solow notes that the contribution of a factor of production in the level and rate of growth of real output depends on the relative "importance" of the factor of production (i.e., the input ratio) and its relative share in output. Although labor still is an important factor in tobacco production, its relative share has been decreasing. Thus, capital and technology seem to have made an increasing contribution to the level of real output of tobacco, even when the latter has remained relatively constant during the period 1949-1976.

THE THEORETICAL MODEL

Most studies related to agricultural production functions use the Cobb-Douglas form. However, the Cobb-Douglas production function yields constant relative factor shares, even with changes in relative factor prices and factor ratios, because the elasticity of factor substitution (σ) is forced to unity. In recent years, the CES production function has been used more frequently as it enables one to estimate the elasticity of factor substitution and the bias of technological progress simultaneously (Arrow et al., Ferguson and Moroney, Lianos, Martin and Havlicek, Srivastava and Heady).

For purposes of this study, a CES production function of the factor augmentation form under constant returns to scale is used. Symbolically,

$$(8) \quad Y = ([\alpha(t)K]^{-\varrho} + [\beta(t)L]^{-\varrho})^{-1/\varrho}.$$

To facilitate statistical estimation, it is assumed that factor augmentation occurs at a constant exponential rate.[4] Let

$$(9) \quad \alpha(t) = \alpha_0 t^{\gamma k}, \text{ and } \beta(t) = \beta_0 t^{\gamma 1} \ (\gamma k, \gamma 1 > 0).$$

Substituting equation 9 in 8 gives

$$(10) \quad Y = [(\alpha_0 t^{\gamma k} K)^{-\varrho} + (\beta_0 t^{\gamma 1} L)^{-\varrho}]^{-1/\varrho}$$

where

ϱ = the substitution parameter
$t^{\gamma k}$, $t^{\gamma 1}$ = rates of factor augmentation over time for capital and labor, respectively
Y = output
L = labor
K = capital.

For equation 10, the marginal physical product of labor is given by

$$(11) \quad f_L = \frac{\partial Y}{\partial L} = \left(\frac{Y}{L}\right)^{1+\varrho} (\beta_0 t^{\gamma 1})^{-\varrho}.$$

Assuming perfect competition, we can set the marginal physical product of labor equal to the real wage rate, w. Rewriting, we have

$$(12) \quad w = \left(\frac{Y}{L}\right)^{1/\sigma} (\beta_0 t^{\gamma 1})^{1-1/\sigma}$$

because $1 + \varrho = \frac{1}{\sigma}$ and, therefore, $-\varrho = 1 - \frac{1}{\sigma}$ (where σ is the elasticity of factor substitution). Rearranging, and then multiplying both sides of equation 12 by w, we find that the relative share of labor equals

$$(13) \quad S_L = \frac{w \cdot L}{Y} = (\beta_0 t^{\gamma 1})^{\sigma-1} (w)^{1-\sigma}.$$

[4]This procedure has been used in several studies, including those of Ferguson and Moroney and of Lianos.

Finally, converting into logarithms gives

$$\text{(14)} \qquad \log S_L = (\sigma-1)\log \beta_o + (1-\sigma)\log w + \gamma 1(\sigma-1)\log t.$$

The elasticity of substitution, σ, can be obtained from equation 14.

Using the production function in equation 10, we can express the ratio of the marginal products of labor and capital as

$$\text{(15)} \qquad \frac{f_L}{f_K} = \left(\frac{\beta_o}{\alpha_o} t^{\gamma 1-\gamma k}\right)^{-\varrho} \left(\frac{K}{L}\right)^{1+\varrho}.$$

Substituting w/r for f_L/f_K, and solving for K/L gives

$$\text{(16)} \qquad \frac{K}{L} = \left(\frac{w}{r}\right)^{\sigma} \left(\frac{\beta_o}{\alpha_o} t^{\gamma 1-\gamma k}\right)^{1-\sigma}$$

because $\sigma = \frac{1}{(1+\varrho)}$ and, therefore, $\varrho/(\varrho+1) = 1-\sigma$

Converting into logarithms, we can rewrite equation 16 as

$$\text{(17)} \qquad \log\left(\frac{K}{L}\right) = (1-\sigma)\log\left(\frac{\beta_o}{\alpha_o}\right) + \sigma \log\left(\frac{w}{r}\right) + (\gamma 1-\gamma k)(1-\sigma)\log t.$$

From this equation we can obtain estimates for σ as well as $(\gamma 1-\gamma k)$. We can then estimate B as follows, using the approach of Lianos (p. 419).

$$\text{(18)} \qquad B = \frac{\sigma-1}{\sigma}(\gamma k-\gamma 1).$$

Note, however, that σ can be estimated by equation 14 without using data on capital and interest rate. Because proxy data were used for capital, the estimate of σ may be more reliable from equation 14. Equation 18 was used primarily for the estimation of B.

EMPIRICAL RESULTS

Data

To estimate equations 14 and 17, data on the value of tobacco output (Y), wage rate (w), man-hours (L), interest rate (r), and capital (K) were obtained for the time period 1949-1976 (USDA sources). Wage rates were deflated by the index of prices paid by farmers for family living (1967 = 100). Wages were assumed to be used primarily for meeting family living expenses rather than for paying production expenses. Correspondingly, the value of output was deflated by the index of prices received by farmers, and interest rate by prices paid by farmers for operating expenses (1967 = 100). From these data the relative share of labor was estimated. As a proxy for capital, an index of PCA production loans in the tobacco region was computed.[5]

Estimates of S_L, σ, $(\gamma_1-\gamma_k)$, and B

The model for equation 14 can be rewritten as follows after inclusion of an error term.

$$\text{(19)} \qquad \log S_L = (\sigma-1)\log \beta_o + (1-\sigma)\log w + \gamma 1(\sigma-1)\log t + \varepsilon_t.$$

It was assumed that ε_t is lognormally distributed.

TABLE 1. WAGE RATES, MAN-HOURS, VALUE OF PRODUCTION AND THE RELATIVE SHARE OF LABOR FOR U.S. TOBACCO PRODUCTION 1949-1976

Year	Real Wage Rate	Man-Hours in Tobacco	Real Value of Tobacco	Relative Share of Labor
	($/ hr.)	(million)	($ million)	
1949	0.9067	747	1149.34	0.5893
1950	0.9079	745	1281.83	0.5277
1951	0.9277	837	1307.71	0.5938
1952	0.9643	820	1269.77	0.6227
1953	0.9762	746	1228.72	0.5927
1954	0.9643	772	1306.18	0.5699
1955	0.9762	710	1285.16	0.5393
1956	1.0118	663	1252.78	0.5355
1957	1.0000	524	989.42	0.5296
1958	1.0337	515	1097.46	0.4851
1959	1.0674	539	1104.36	0.5210
1960	1.0778	549	1252.70	0.4723
1961	1.1000	567	1387.09	0.4496
1962	1.1099	606	1443.20	0.4660
1963	1.1413	591	1427.72	0.4724
1964	1.1613	546	1365.36	0.4644
1965	1.2000	468	1209.15	0.4645
1966	1.2551	440	1181.46	0.4674
1967	1.3300	409	1315.50	0.4135
1968	1.3846	350	1159.62	0.4179
1969	1.4220	341	1216.46	0.3986
1970	1.4386	309	1258.43	0.3532
1971	1.4661	264	1176.15	0.3291
1972	1.4959	241	1218.53	0.2959
1973	1.5038	245	1165.14	0.3126
1974	1.5166	261	1349.08	0.2934
1975	1.4639	287	1279.59	0.3283
1976	1.5114	175	1313.62	0.3164

Sources: USDA (*Agricultural Statistics, Tobacco Situation*, and *Tobacco in the United States*).

From data presented in Table 1, the following estimates were obtained using ordinary least squares (general linear model).

$$\text{(20)} \qquad \log S_L = \underset{(0.065)}{-0.670} - \underset{(0.064)}{1.322}\log w + \underset{(0.035)}{.030}\log t.$$

$$R^{-2} = 0.903$$
$$DWS = 0.909$$
$$df = 27$$
$$\hat{\sigma} = 2.32$$

[5]PCA loans are primarily used for operating expenses. However, for lack of data on long-term durable assets (e.g., bulk barns, harvesters), PCA loans were used as a proxy for capital. Indebtedness is expressed to an anonymous *Journal* reviewer for making this point.

The standard errors of the coefficients are given in parentheses. The coefficient for the real wage variable is highly significant and the Durbin-Watson statistic is fairly high in comparison with that found in similar studies. The elasticity of factor substitution estimated from equation 20 is 2.32.

The statistical model for the estimation of $(\gamma_1-\gamma_k)$ and B can be rewritten as

$$(21)\quad \log\left(\frac{K}{L}\right) = (1-\sigma)\log\left(\frac{\beta_o}{\alpha_o}\right) + \sigma\log\left(\frac{w}{r}\right) + (\gamma_1-\gamma_k)(1-\sigma)\log t + \varepsilon_t.$$

Using data on interest rate and capital, along with other data, we obtained the following results

$$(22)\quad \log\left(\frac{K}{L}\right) = \underset{(0.919)}{0.072} + \underset{(0.382)}{2.198}\log\left(\frac{w}{r}\right) + \underset{(0.126)}{.747}\log t$$

$R^{-2} = 0.915$
DWS = 0.487
df = 27
$\hat{\sigma} = 2.198$

$$(23)\quad (\gamma_1-\gamma_k) = \frac{\alpha_2}{1-\sigma} = \frac{.747}{-1.198} = -.624$$

$$(24)\quad B = \frac{\hat{\sigma}-1}{\hat{\sigma}}(\gamma_k-\gamma_1) = \frac{1.198}{2.198}(.624) = .3401.$$

The estimate for σ obtained from equation 22 is very close to that obtained from 20. The results from equation 24 indicate that B is labor-saving (i.e., capital-using). It also indicates that the productivity of capital in tobacco production has increased more than the productivity of labor. Thus, at any factor price ratio, w/r, producers are induced to substitute capital for labor, i.e., to increase the capital-labor ratio.

An alternative method of evaluating the elasticity of substitution can be derived from Allen's formula for elasticity of factor demand (p. 373).[6] In the notation of this study:

$$(25)\quad \sigma = \frac{-[S_L(\eta)] - E_L}{1 - S_L}$$

where η is the price elasticity of output demand and E_L is the price elasticity of demand for labor.

Assuming that the price elasticity of demand for cigarettes can be used as a proxy for that of tobacco, one can use the estimates provided by Hamilton. He estimated the elasticity of demand for cigarettes to be −0.511. Ganguly and Thompson estimated the price elasticity of demand for hired labor in tobacco production to be −0.59. With these proxy parameters and the mean S_L of 0.45 for the period 1949-1976, equation 15 gives an estimate of $\sigma = 1.5$. Although lower than estimates presented above, this value is consistent with those obtained from equations 20 and 22.

A high elasticity of factor substitution indicates the relative ease with which labor can be substituted by capital. Coupled with a labor-saving bias of technological change, it has resulted in a gradual decline in the relative share of labor in tobacco production. Several studies on tobacco confirm the labor-saving bias of technological change (Grise et al., Hoff et al.). The growing use of labor-saving technology (self-propelled and pull-type multipass harvesters, low-profile once-over harvesters, bulk racks, and bulk barns) has been quickened by rapidly increasing wage rates, uncertainty of obtaining labor for harvesting-curing operations, the need and desire to expand, and decline in the relative price of machinery.

SUMMARY AND CONCLUSIONS

It is evident that the relative share of labor in U.S. tobacco production has declined in spite of a continuous increase in wage rates. The relative ease of substitution of capital for labor (the high elasticity of substitution) and the labor-saving bias of technological change explain this trend. Given the current state and level of technology, one can project that the relative share of labor in this sector will decline further in the near future. Because the demand for labor is very high during harvesting-curing operations, wage rates are expected to rise further and more farms can be expected to mechanize to prevent average production costs from increasing.

The decline in the relative share of labor, however, does not imply that laborers working in tobacco production are worse off than before. One must consider their total earnings from tobacco production, as well as from other sources. Moreover, the adjustment process of workers displaced from this sector must be studied before any final conclusions can be drawn in this regard.

[6] Martin and Havlicek also use Allen's procedure. However, their equation 12 should read

$$E_L = -[(1-S_L)(\sigma) + (S_L)(\eta)].$$

REFERENCES

Allen, R. G. D. *Mathematical Analysis for Economists.* London: The Macmillan Press Ltd., 1971.

Arrow, K. J., H. B. Chenery, B. Minhas, and R. M. Solow. "Capital Labor Substitution and Economic Efficiency." *Rev. Econ. Statist.* 43 (1961):225-50.

Ferguson, C. E. *The Neoclassical Theory of Production and Distribution.* Cambridge: Cambridge University Press, 1969.

_____ and J. R. Moroney. "The Sources of Change in Labor's Relative Share: A Neoclassical Analysis." *S. Econ. J.* 35(1969):308-22.

Ganguly, Pradeep and C. Stassen Thompson. *The Nature of the Demand Function for Hired Labor in Tobacco Production: A Case for Output-Constant Demand Function.* Department of Agricultural Economics and Rural Sociology, Clemson University, WP 4379, April 1979.

Grise, V. N., O. K. Shugars, W. D. Givan, and F. L. Hoff. *Structural Characteristics of Flue-Cured Tobacco Farms and Prospects for Mechanization.* USDA, ERS, AER No. 277, Jan. 1975.

Hamilton, James L. "The Demand for Cigarettes: Advertising, the Health Scare, and the Cigarette Advertising Ban." *Rev. Econ. Statist.* 54(1972):401-11.

Hoff, F. L., W. D. Givan, O. K. Shugars, and V. N. Grise. *Flue-Cured Tobacco Mechanization and Labor: Impacts of Alternative Production Levels.* USDA, ERS, AER No. 368, Jan. 1977.

Kravis, Irving B. "Relative Income Shares in Fact and Theory." *Am. Econ. Rev.* 49(1959):917-49.

Lianos, Theodore P. "The Relative Share of Labor in United States Agriculture, 1949-1968." *Am. J. Agr. Econ.* 53(1971):411-22.

Mann, Charles K. *Tobacco: The Ants and the Elephants.* Utah: Olympus Publishing Co., 1975.

Martin, M. A. and J. Havlicek, Jr. "Technological Change and Labor's Relative Share: The Mechanization of U.S. Cotton Production." *S. J. Agr. Econ.* 9(Dec. 1977):137-41.

Ruttan, V. and Thomas T. Stout. "Regional Differences in Factor Shares in American Agriculture: 1925-1957." *J. Farm Econ.* 42(1960):52-68.

Solow, Robert M. "Resources and Economic Growth." *Am. Economist.* 22(1978):5-11.

Srivastava, U. K. and E. O. Heady. "Technological Change and Relative Factor Shares in Indian Agriculture: An Empirical Analysis." *Am. J. Agr. Econ.* 55(1973):509-14.

U.S. Department of Agriculture. *Agricultural Statistics,* annual issues.

______, Agricultural Marketing Service. *Tobacco in the United States,* recent issues.

______, Economics, Statistics and Cooperatives Service. *Tobacco Situation,* recent issues.