Cotton

1977

TECHNOLOGICAL CHANGE AND LABOR'S RELATIVE SHARE: THE MECHANIZATION OF U.S. COTTON PRODUCTION*

Marshall A. Martin
Joseph Havlicek, Jr.**

* Contributed Paper, American Agricultural Economics Association Meetings, Town and Country Motel, San Diego, California, July 31 - August 3, 1977.

** Marshall A. Martin, Assistant Professor, Department of Agricultural Economics, Purdue University, West Lafayette, Indiana, and Joseph Havlicek, Jr., Professor, Department of Agricultural Economics and Department of Statistics, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Technological Change and Labor's Relative Share: The Mechanization of U.S. Cotton Production

In the pre-war period labor's share in the U.S. manufacturing and agricultural sectors was relatively constant. Keynes called this "a bit of a miracle". Several studies (Kravis, and Ferguson and Moroney) have shown that labor's share in the U.S. manufacturing sector has increased in the post-war period. The opposite appears to have been the case for U.S. agriculture. Two recent studies (Ruttan and Stout, and Lianos) indicate that labor's relative share in the U.S. agricultural sector has declined in the post-war period.

There has been a substantial substitution of capital for labor in both the manufacturing and agricultural sectors in the post-war period. The secular increase in the wage-rental ratio has encouraged the substitution of capital for labor. However, while this argument alone, might explain the observed decline in labor's share in the agricultural sector, it does not explain what has occurred in the manufacturing sector. Moreover, this argument excludes another important characteristic of both sectors in the post-war period; technological change.

The adoption of labor-saving technology has been quite rapid in the U.S. agricultural sector during the last several decades (Hayami and Ruttan). The most rapid rate of substitution of machinery for labor in the agricultural sector has occurred in the South. Kaneda notes that the recent high rate of technical change in the Southeast and Delta regions are largely reflections of the rapid mechanization of cotton production in the last decade or so.

This article has two objectives: a) to demonstrate why the elasticity of factor substitution and the bias of the technical change both must be known in order to determine labor's relative share and b) to empirically test whether cotton labor's relative share in fact fell as a result of the adoption of mechanical cotton pickers.

Elasticity of Factor Substitution and Technological Progress

Factor shares are dependent on two important parameters: a) the elasticity of factor substitution and b) the bias of the technology being adopted. In this section these two parameters are shown to affect labor's relative share. The analysis is based on two pervasive assumptions: a) the production function is homogeneous of degree one with two homogeneous inputs, K (capital) and L (labor) and b) perfect competition prevails in both the input and output markets.

The output for a given industry is represented by a production function, $Y = f(K, L, t)$. Over the relevant range of production, both marginal products are strictly postive ($f_K > 0$, $f_L > 0$) and both decrease monotonically ($f_{KK} < 0$, $f_{LL} < 0$, and $f_{KL} > 0$).

Each factor is paid its marginal product such that Euler's Theorem holds, $Y = f_L L + f_K K$. Hence, $w = f_L$ and $r = f_K$, where w is the wage rate and r is the rental rate for capital equipment. The bias of the technological progress (β) is based on the Hicksian definition where:

(1) $\beta = 1$ Hicksian neutral

$\beta > 1$ Labor-saving (capital-using)

$\beta < 1$ Capital-saving (labor-using)

Technological change which leaves the marginal physical product of labor and capital unchanged is neutral. If the marginal physical product of labor increases more (less) relative to the marginal physical product of capital, it is a capital-saving (labor-saving) technological change.

The elasticity of factor substitution (σ) may be defined as:

(2) $\sigma = \dfrac{d(K/L)}{d(w/r)}$ or $\sigma = \dfrac{f_L \, f_K}{Y \, f_{LK}}$

From Euler's Theorem it follows that the absolute share of capital and labor are Kf_K and Lf_L respectively. And the relative shares of capital and labor would be $R_K = Kf_K/Y$ and $R_L = Lf_L/Y$ respectively.

Differentiating labor's relative share with respect to time gives:

(3) $\dfrac{d(R_L/Y)}{dt} = d(Lf_L/Y)/dt = \left[\dfrac{Y(Lf_{LL} + Lf_{LK} + f_L) - Lf_L \, dY}{Y^2} \right] /dt$

Substituting for Y and dY from Euler's Theorem, expanding, and rearranging terms yields:

(4) $$\frac{d(R_L/Y)}{dt} = \frac{1}{Y^2} \left[Kf_K(f_L \, dL/dt + Lf_{LL} \, dL/dt + Lf_{LK} \, dK/dt) - Lf_L \, (f_K \, dK/dt + Kf_{KK} \, dK/dt + Kf_{KL} \, dL/dt) \right]$$

Technical progress over time may be defined as:

(5) $\beta\lambda = 1/L \cdot dL/t = \beta \cdot 1/K \cdot dK/dt$

where λ is the time derivative of technical change.

Now partially differentiating Euler's Theorem with respect to L yields:

(6) $\dfrac{\partial Y}{\partial L} = Kf_{KL} + Lf_{LL} + f_L$

Rearranging terms in (6) and using the definition of the marginal product of labor ($\partial Y/\partial L = f_L$) gives:

(7) $f_{KL} = - Lf_{LL}/K$

In a similar fashion the partial derivative of Euler's Theorem with respect to K is:

(8) $f_{KL} = Kf_{KK}/L$

Substituting definitions (2) and (5) and the derivations from (6), (7) and (8), into (4), with some rearranging of terms, yields:[1/]

$$(9) \quad \frac{d(R_L/Y)}{dt} = R_L R_K \quad \lambda(\beta - 1) \left(\frac{\sigma - 1}{\sigma}\right)$$

By definition labor and capital's absolute shares (R_L and R_K) are positive. Also λ, the proportional increase in the effective quantity of K (capital) per unit of time is positive. Hence, labor's relative share is determined by two parameters: a) the bias of the technological change (β) and b) the elasticity of factor substitution (σ).

If either β or σ is equal to one, then any change in the quantity of labor used will have no effect on labor's relative share. However, if β is greater than one (labor-saving technological change), the substitution of capital for labor will only decrease labor's relative share if σ is greater than one. If β is greater than one and σ is less than one, a decrease in the use of labor will increase labor's relative share! The converse would be true when β is less than one (capital-saving technological change). A summary of the results may be found in Table 1.

The key point is that the displacement of labor with a labor-saving technology in a given industry would only decrease labor's relative share in that industry if the elasticity of substitution is greater than one. This was precisely what Lianos found to be the case for the U.S. agricultural sector as a whole for the post-war period.

Ferguson and Moroney, however, found that in spite of the adoption of labor-saving technology in most industries in the U.S. manufacturing sector, capital deepening accompanied by an inelastic elasticity of factor substitution resulted in an increase in labor's relative share.

Table 1

Labor's Relative Share, the Elasticity of Substitution, and the Bias of Technological Change

σ	β	Change in Labor's Relative Share with a Decrease in Labor Use
$= 1$		No Change
	$= 1$	No Change
> 1	> 1	Decrease
> 1	< 1	Increase
< 1	> 1	Increase
< 1	< 1	Decrease

U.S. Cotton Labor's Relative Share: An Empirical Example

Rather extensive investigations have been made of changes in factor shares for selected industries within the U.S. manufacturing sector. This has not been the case for the crops or livestock components of the U.S. agricultural sector.

The mechanization of cotton production in the U.S. has been quite rapid. Cotton production was traditionally one of the most labor-intensive of the major crops. A major portion of the labor input in cotton production in the pre-war period was required for the harvesting operation.[2/] The introduction of mechanical cotton harvesters after World War II reduced labor requirements in harvesting by approximately 95 percent (Maier).

The rate of adoption of mechanical harvesters was quite rapid. In 1946 only one percent of the cotton grown in the U.S. was mechanically harvested. By 1970 virtually all (97 percent) U.S. cotton production was picked mechanically.

For most of the family and hired workers who had been employed in the production of cotton, this meant the end of agricultural employment and compelled many of them to eventually go to towns and cities, mostly in the North, to live and seek employment. The rural-urban migration has meant difficult socio-economic adjustment problems for the migrants and the cities which were affected. For cotton farmers, the capital-intensive nature of the new technology drastically altered the organization and operations of their farms.

The question addressed in this section, however, is: What happened to labor's relative share within the cotton sector? Real farm wages in the

South increased 50 percent from 1952 to 1969, the period of the most rapid rate of adoption of cotton pickers, while man-hours devoted to cotton production fell over 80 percent. Furthermore, the real value of cotton production, including acreage diversion transfer payments, also fell by nearly 60 percent. However, labor's relative share (S_L) in the cotton sector fell from 0.39 in 1952 to 0.22 in 1969, a decline of 42 percent (Table 2).

The derivation in the previous section would suggest that, given a labor-saving technological change in the cotton sector, a decline in labor's relative share would require an elasticity of factor substitution greater than one.

Satisfactory time series data on the stock of capital invested in machinery used in cotton production are not available. Thus, it is not possible to estimate the elasticity of factor substitution (σ) from a CES production function using the capital-labor ratio and the wage-rental ratio as explanatory variables. However, it is feasible with the data available, to use two other alternative approaches to estimate σ.

The CES production function may be expressed as:

$$(10)\quad Y = \left| (\alpha_o\ t^{\gamma k}\ K)^{-\rho} + (\beta_o\ t^{\gamma \ell}\ L)^{-\rho} \right|^{-1/\rho}$$

where Y = output, K = capital, L = labor, ρ = substitution parameter, α_o, β_o = distribution parameters, and $t^{\gamma k}$, $t^{\gamma \ell}$ = rate of factor augmentation for capital and labor respectively (Lianos).

Differentiating (10) with respect to labor (L) yields:

$$(11)\quad \partial Y/\partial L = (Y/L)^{1+\rho}\ (\beta_o\ t^{\gamma \ell})^{-\rho}$$

Assuming the real wage rate (w) is equal to the marginal physical product of labor ($\partial Y/\partial L$), rearranging the terms in (11), and converting to logarithms gives:

Table 2

Wage Rates, Man-hours, Value of Production, and Labor's Relative Share for U.S. Cotton Production, 1952-1969.

Year	Real Wage Rate/Hour[a/]	Man-hours Cotton-Labor (millions)	Real Value Output Including Acreage Diversion Payments ($ million)[b/]	Labor Share[c/] (S_L)
1952	0.5710	1655	2446.4	0.3863
1953	0.5978	1609	2736.8	0.3515
1954	0.5905	1269	2407.3	0.3113
1955	0.6043	1235	2655.2	0.2811
1956	0.6335	1074	2389.8	0.2847
1957	0.6253	818	1787.8	0.2861
1958	0.6220	769	2015.1	0.2374
1959	0.6330	911	2586.2	0.2230
1960	0.6433	831	2861.7	0.1868
1961	0.6540	772	2677.6	0.1886
1962	0.6603	679	2648.6	0.1693
1963	0.6720	647	2816.0	0.1544
1964	0.6958	573	2614.0	0.1525
1965	0.7155	483	2212.3	0.1562
1966	0.7405	309	1324.6	0.1727
1967	0.7935	242	1397.3	0.1374
1968	0.8308	275	1446.7	0.1579
1969	0.8615	279	1045.2	0.2230

Source: Various United States Department of Agriculture publications.

a/ Average of four major cotton regions: South Atlantic, East South Central, West South Central, and Pacific. Deflated by Prices Paid by Farmers Index, 1947-49 = 100.

b/ Deflated by Wholesale Price Index, 1947-49 = 100. The price used is a composite of the market price and the support price based upon cotton program participation.

c/ Column one multiplied by column two divided by column three.

(12) $\log S_L = (\sigma-1) \log \beta_o + (1-\sigma) \log w + \gamma\ell(\sigma-1) \log t$

Based upon the data in Table 2 the following estimates were obtained by ordinary least squares.3/

$$\text{(13)} \quad \log S_L = \underset{}{-0.473} - \underset{(0.478)}{0.509} \log w - \underset{(0.062)}{0.336} \log t \qquad R^2 = .90 \quad d' = 1.056$$

Although the Durbin-Watson (d') is in the inconclusive range and the coefficient of the real wage variable is only significant at the 0.15 level, the statistical results are consistent with a priori expectations. The elasticity of factor substitution is 1.5. The rate of factor augmentation is -.66 which is indicative of a reduction over time in labor employment in cotton production.

An alternative method of estimating the elasticity of factor substitution is suggested by R. G. D. Allen (p. 373).

(14) $E_L = -(1 - S_L)(\sigma) + (S_L)(\eta)$

where E_L = price elasticity of demand for labor, S_L = labor's relative share, η = price elasticity of product demand, and σ = elasticity of factor substitution.

Tyrchniewicz and Schuh report a long-run price elasticity of demand for hired farm labor in the United States of -.49 and for unpaid family labor of -3.0. Wallace and Hoover estimated a price elasticity of demand for hired and family farm labor of -1.433. Unpaid family labor and operator labor represent a major portion of the traditional share-cropper cotton labor force which has been replaced with the modernization of cotton production.4/ Hence, long-run price elasticities of demand for cotton labor of -1.0 and -1.5 appear to be reasonable estimates.

Blakley and Martin's estimates of the price elasticity of demand for cotton are -.86 and -.89 respectively. Cotton labor's average relative share for the period 1952-1969 is 0.23.

Using these parameter estimates, the Allen formula gives values between 1.0 and 1.7 for the elasticity of factor substitution. These estimates are consistent with what one would expect based on the derivations in the first section and the previous estimate of σ. Furthermore, these results for the U.S. cotton industry are consistent with Lianos estimates for the U.S. agricultural sector as a whole in the post-war period.

Summary and Conclusions

Labor's relative share in a sector of an economy or industry within a sector has been studied by economists for several decades. Empirical studies of the U.S. manufacturing sector as well as selected industries in the sector suggest that labor's relative share has been increasing in the post-war period. Other studies indicate that the opposite has been the case for the U.S. agricultural sector.

This paper demonstrates why empirical estimates of both the elasticity of factor substitution and the bias of the technology being adopted must be known before labor's relative share can be ascertained. Secondly, the U.S. cotton sector is used as a case study to illustrate why the adoption of mechanical cotton pickers contributed to a decline in labor's relative share in that industry in the post-war period.

One concluding caveat is in order. A decline in labor's relative share in a particular industry or within a given sector does not necessarily mean that labor is worse off. Workers may be able to obtain employment in another sector. Moreover, the labor share analysis presented in this paper is based on the functional distribution of income. It does not explain the personal distribution of income.

Footnotes

1/ For more detail on the algebra involved in this derivation see Johnson and Martin.

2/ The other labor-intensive activity was "chopping" cotton. This operation has also been largely mechanized.

3/ The standard errors are contained in parentheses under their respective regression coefficients.

4/ In 1959 about 15 percent of the U.S. cotton crop was grown by 65 percent of the cotton producers. These farms relied heavily on family and operator labor (Day).

References

Allen, R.G.D. Mathematical Analysis for Economists. New York: St. Martin's Press, 1962.

Blakley, Leo V. "Quantitative Relationships in the Cotton Economy with Implications for Economic Policy." Tec. Bull. T-95, Oklahoma State University, Agr. Exp. Sta., 1962.

Day, Richard H. "The Economics of Technological Change and the Demise of the Sharecropper." Amer. Econ. Rev. 57(1967):427-449.

Ferguson, C.E. and John R. Moroney. "The Sources of Change in Labor's Relative Share: A Neoclassical Analysis," S. Econ. J. 35(1969): 308-322.

Hayami, Yujiro and Vernon W. Ruttan. Agricultural Development, An International Perspective. Baltimore, Md.: Johns Hopkins Press, 1971.

Johnson, Harry. The Two Sector Model of General Equilibrium. Chicago: Aldine Atherton, 1971.

Kaneda, Hiromitsu. "Regional Patterns of Technical Change in U.S. Agriculture, 1950-1963." J. Farm Econ. 49(1967):199-212.

Kravis, Irving B. "Relative Income Shares in Fact and Theory." Amer. Econ. Rev. 49(1959):917-949.

Lianos, Theodore P. "The Relative Share of Labor in United States Agriculture, 1949-1968." Amer. J. Agr. Econ. 53(1971):411-422.

Maier, Frank H. "An Economic Analysis of Adoption of the Mechanical Cotton Picker." Ph.D. thesis, University of Chicago, 1969.

Martin, Marshall A. "The Income Distribution Impacts of the Adoption of Mechanical Harvesting of Cotton in the United States." M.S. thesis, Purdue University, 1972.

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

Tyrchniewicz, Edward W. and G.E. Schuh. "Econometric Analysis of the Agricultural Labor Market." Amer. J. Agr. Econ. 51(1969):770-787.

U.S. Department of Agriculture. Agricultural Statistics. Washington, D.C., various issues.

U.S. Department of Agriculture. Farm Labor. Washington, D.C., various issues.

U.S. Department of Agriculture. Statistics on Cotton and Related Data 1930-1967. Bull. No. 417, Washington, D.C. 1968.

Wallace, T. D. and Dale M. Hoover. "Income Effects of Innovation: The Case of Labor in Agriculture." J. Farm Econ. 48(1966):325-336.