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The Cotton Harvester in Retrospect: Labor Displacement or Replacement?

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The prevailing view of new mechanical technology is that it has, in large part, pushed labor out of agriculture. An alternative hypothesis is that labor has been pulled out of agriculture by higher wages in nonfarm occupations. The mechanical cotton harvester is used to test the two hypotheses. Estimation of a simultaneous-equation model of the labor market for cotton pickers reveals 79 percent of the reduction in hand picking of cotton was due to increased nonfarm wages—the pull effect; the remaining 21 percent is attributed to the decreased cost of machine harvesting—the push effect.

FROM 1930 to 1980 the U.S. farm labor force declined by about two-thirds, and the machinery-labor ratio increased nearly tenfold. The large-scale substitution of capital for labor in U.S. agriculture is well known, but the reasons for this phenomenon are not. In much of the recent economics literature the prevailing view appears to be that new mechanical technology has displaced or pushed labor out of agriculture. As noted by James Holt, "A bedrock proposition of conventional agricultural wisdom is that agricultural employment has steadily declined in the United States. In the 1950s and 1960s this decline was especially dramatic due to an explosion of *labor-displacing* agricultural production technologies."[1]

Richard Day's 1967 paper can be taken as the most forceful argument in support of the hypothesis that mechanization was responsible for "labor push" out of agriculture.[2] Day studied developments in the Mississippi Delta and attributed most of the reduction in the demand for labor to the mechanization of cotton harvesting. We reexamine the

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[1] James S. Holt, "Labor Market Policies and Institutions in an Industrializing Agriculture" *American Journal of Agricultural Economics*, 64 (Dec. 1982), pp. 999–1006. Quote from p. 999 (emphasis added).

[2] Richard H. Day, "The Economics of Technological Change and the Demise of the Sharecropper," *American Economic Review*, 57 (June 1967), pp. 427–49.

mechanization of cotton harvesting in the South, and critically evaluate much of the labor-displacement literature.[3]

Two other hypotheses have been advanced to explain capital-labor substitution. One, due mainly to Hans Binswanger, can be interpreted as suggesting that on-the-farm technical change in agriculture is the major cause of the mechanization process.[4] Elsewhere we have argued that Binswanger's explanation is in error; it rests on a misspecification of the induced innovation hypothesis in its application to a single sector and uses questionable data.[5] Our conclusion was that technological change, internal to the farm sector, cannot explain the revolutionary magnitude of the postwar farm mechanization.

The third hypothesis is that rising wages in nonfarm occupations have drawn labor out of agriculture and new labor-saving technology was developed and adopted in reaction to this outmigration to replace the people who left farms in search of higher earnings elsewhere. While under the two earlier hypotheses labor is viewed as being pushed out of agriculture by a reduction in demand for its services, under the third labor is pulled out because of a decrease in supply. Our analysis estimates the relative contribution of the two factors—new mechanical technology that lowered demand for labor, on the one hand, and rising urban wages that decreased supply, on the other—to the reduction in the farm labor employment in cotton harvesting. We view this as the most appropriate test of the labor-push hypothesis, and conclude from the empirical evidence that the pull effect is almost four times stronger than the push effect.

The issue addressed is of more than academic interest. If labor has in fact been pushed out of agriculture, then the research establishment and farm machinery companies share responsibility for the social costs of the large-scale migration of farm people. In this case a concern by the government over job loss in agriculture would be legitimate. On the other hand, if labor has been pulled out by higher earnings in nonfarm occupations, research institutions and machinery manufacturers can be viewed as responding to market forces. Public action to counteract these forces would probably harm society more than it would help by reducing growth in real income.

[3] Other studies in which agricultural labor is implicitly or explicitly assumed to be in large part displaced by machines include: Paul Barnett, et al. "Labor's Dwindling Harvest," California Institute for Rural Studies, University of California, (Davis, 1978); Ray Marshall, *Rural Workers in Rural Labor Markets*, (Salt Lake City, 1974); Harland Padfield and William E. Martin, *Farmers, Workers and Machines*, (Tucson, 1965); Andrew Schmitz and David Seckler, "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester," *American Journal of Agricultural Economics*, 52 (Nov. 1970), pp. 569–77.

[4] Hans P. Binswanger, "Measured Biases of Technical Change: The United States," in *Induced Innnovation, Technology, Institutions and Development*, Hans P. Binswanger, Vernon W. Ruttan et al., eds. (Baltimore, 1978).

[5] Yoav Kislev and Willis Peterson, "Induced Innovations and Farm Mechanization," *American Journal of Agricultural Economics*, 63 (Aug. 1981), pp. 562–65.

I

It will be useful to compare the results of our empirical approach with Day's method of analysis which was to "replay the history" of the Mississippi Delta. Using a recursive programming model, Day simulated the optimal combinations of crops, inputs, and technologies for each year successively over the 1940 to 1959 period. Among the constraints of the programming model were the available resources. A factor supply was regarded as "tight," relative to demand, in years in which its constraint was binding; otherwise, a surplus was indicated. In the context of the model, labor was in short supply between 1941 and 1949, partly due to war shortages. Afterwards employment in the programmed economy fell sharply, the corresponding yearly constraints were not binding, and the implication was "that such migration as may have occurred [out of the region] was induced more by a push than by a pull effect."[6]

It appears, however, that Day grossly overestimated the contribution of the mechanization of cotton harvesting to the reduction in employment. According to his model 100 percent of the cotton in the Delta was harvested by machine in 1957 (see his fig. 2), while in fact only 17 percent of the cotton was harvested mechanically in Mississippi during that year.[7] The 100 percent level was not attained until 1975.

Technologies, and machine harvesting among them, were introduced into Day's model as they became historically available, together with the corresponding per-unit cost estimates. Relative cost effectiveness determined the rate of diffusion of the capital-intensive technologies (subject to some dynamic constraints) and thus determined the reduction in labor demand. As we will later point out, it is very difficult to estimate actual costs accurately because of depreciation, capital costs, performance, repair components, and income-tax considerations. An alternative approach is to use market prices for machine services; we use custom rates as a measure of these prices.[8] Before 1957 custom rates for machine picking in Mississippi exceeded piece rates for hand picking (as can be seen later in Tables 2 and 3). Given these data, it is not surprising that, in fact, only a small proportion of cotton was picked by machine in Mississippi prior to 1957. Only after that year did custom rates fall below piece rates, with the latter starting to increase slightly. Before that time it would have been irrational for farmers to use machines extensively to harvest cotton because labor was cheaper.

Even if Day's model had replayed history accurately, it is important to recognize that it does not constitute a valid test of the labor-push-by-

[6] Day, "The Economics of Technological Change . . . ", p. 441.
[7] USDA, Economic Research Service, *Statistical Bulletin* No. 535, "Statistics on Cotton and Related Data, 1920–1973" (Washington, D.C., 1974), p. 218.
[8] Prices paid by farmers to owners of mechanical cotton harvesters for harvesting services.

machine hypothesis. Between 1950 and 1957, and coinciding with the increased use of synthetic fibers, the real price received by farmers for cotton in Mississippi declined by 35 percent while cotton acreage in the state decreased by one-third. The decline in cotton acreage, and to some extent the replacement of cotton by less labor intensive crops such as soybeans, are reflected in Day's results as a decrease in the demand for labor. But the resulting surplus of labor should not be attributed entirely to the increased use of machines. Unfortunately the emphasis in the article on the effects of technological change in agriculture leads at least the casual reader to this conclusion. Also, as we point out later, real piece rates for hand picking of cotton increased dramatically during World War II and were "out of line" with other wages at the end of the war. An adjustment in this labor market was to be expected during the 1950s.

II

Hand harvesting of cotton was regarded as one of the more arduous tasks in agriculture even when farming was characterized by back-breaking work. Efforts to mechanize the task go back to the early nineteenth century; the first patent on a mechanical cotton harvester was issued in 1850.[9] But cotton proved a very difficult crop to harvest mechanically. The development of a commercially viable machine to harvest cotton took nearly a century.

During the process of development, six different types of machines evolved: pneumatic machines, threshing machines, chemical processes, electrical devices, stripping machines, and spindle pickers.[10] The first patent on the pneumatic machine was granted in 1859. Machines of this type generally consisted of a vacuum tank with attached hoses that a crew of operators would apply to the cotton balls, sucking the cotton into a tank. Work on this type of machine continued into the 1920s, but the machine was finally abandoned after it was determined that an experienced person could pick cotton faster by hand than with the machine.

The threshing machine was designed along the lines of its grain harvesting counterpart. The entire cotton plant was fed into the machine for the purpose of separating the bolls from the rest of the cotton plant.

[9] J. L. Watkins, *King Cotton: A Historical and Statistical Review, 1790–1908* (New York, 1908).

[10] For a more detailed description of the early development of the mechanical cotton harvester and of the various types of machines see H. P. Smith, et al., *The Mechanical Harvesting of Cotton*, Texas Agricultural Experiment Station Bulletin 452 (College Station, 1932); James H. Street, *The New Revolution in the Cotton Economy* (Chapel Hill, 1957); Gilbert C. Fite, "Recent Progress in the Mechanization of Cotton Production in the United States," *Agricultural History*, 24 (Jan. 1950), pp. 190–207. The following discussion on the development of the mechanical cotton harvester draws heavily on Smith and Street.

But unlike grain, where the entire plant matures at one time, cotton was not amenable to threshing because the immature bolls had to be fed into the machine along with the mature ones. Hence this machine was also abandoned.

The objective in chemical processing was to extract the cotton seed with a solvent, and then use the rest of the cotton plant as a fiber source, thereby eliminating the need to separate the cotton bolls from the plant. Although the process was claimed to be a laboratory success, it apparently was not a commercially viable option.

In 1869 the inventor of an electrical harvester attempted to apply the principle of electrical attraction to separate the fiber from the boll. However the charge proved too small to detach the cotton. Later attempts to combine the pneumatic and electric charge concepts also ended in failure.

Cotton stripping machines, also known as "strippers" or "sledders" were probably the simplist and the most successful of the machines discussed thus far. First invented in 1871, the early models resembled a picket fence pulled down the row of cotton by a team of horses or mules. Many farmers built their own strippers. Later models employed revolving rolls embedded with teeth to pull the ripe bolls from the plants without injuring the plants or the unripened bolls. These more advanced strippers have been used extensively in the Texas Panhandle and Oklahoma.

Spindle-type machines remove cotton lint from ripened bolls by means of revolving spindles, fingers, or prongs. The first patent on the spindle picker was taken out in 1895 by Angus Campbell. Substantial improvements over the original spindle machines occurred during the next half-century. Probably the most significant breakthrough in post-Campbell technology was made by the Rust brothers (John and Mack). The first Rust machine, patented in 1928, utilized an endless belt fitted with rotating vertical rows of moistened smooth spindles. The belt containing the spindles moved backward at about the forward speed of the machine so that the spindles came into contact with the cotton bolls at a relatively stationary position thereby avoiding injury to the plant and immature bolls. The moistening of the spindles was also an important feature of the Rust machine, facilitating a more thorough harvest by causing the cotton lint to adhere to the spindles.

In spite of its early successes in field trials, the Rust machine never became a commercial success. From the outset the Rust brothers were torn between two conflicting outcomes. They wanted to ease the burden to farm people of hand harvesting that they had known as boys on the family farm in Texas. But they were also concerned that widespread adoption of the machines would displace thousands of small farmers and farm laborers. To mitigate this phenomena they attempted to perfect a smaller horse-drawn machine that would be affordable to small farmers.

But this machine was not widely adopted, and the Rust Company went out of business in 1942—a victim more of economics than technology. As indicated by figures presented in the next section, the mechanical cotton harvester did not become competitive cost-wise with hand harvesting of cotton in the South until well into the 1950s. Post-World War II cotton harvesters manufactured by the major machinery companies utilized the early Rust technology. Thus the technology to harvest cotton mechanically was already available in the late 1920s.

III

The principal prices affecting the cotton-picking labor market and the choice of cotton harvest technology are presented in Figure 1. From 1930 to 1940 real piece rates for hand harvest of cotton increased at about the same rate as manufacturing wages, a proxy for off-farm employment earnings. Farm wages increased relatively little during this period. The onset of World War II precipitated a rapid increase in real cotton prices and piece rates which continued until the end of the war. Relative to both manufacturing wages and farm wages, the wages paid for hand harvest of cotton increased dramatically during World War II. The increase reflected the shortage of labor in the cotton fields during the war (the South lost 20 percent of its farm labor from 1940 to 1945) as well as the attractive prices of cotton. In the post-World War II years real piece rates for hand harvesting declined, but the ratios of piece rates to manufacturing wages and farm wages in 1964 (the last year piece-rate data were collected) were still higher than in 1930.

In spite of the rapid increase in piece rates during World War II, the cost of harvesting cotton by hand remained below the cost of machine harvesting, measured by custom rates.[11] In the 1930s, immediately following the introduction of the Rust machines, the cost of hand harvesting averaged about 25 percent of the cost of harvesting by machine. It is not surprising, therefore, that few machines were sold during the period and that the Rust company went out of business. By the end of World War II, piece rates approached the cost of machine harvesting. No doubt the shortage of labor and the rapid increase in the cost of hand harvesting relative to the cost of harvesting by machine during the war stimulated further development of machines. However, large-scale production of mechanical cotton harvesters could not begin until the economy returned to a peacetime basis. Even during the first half of the 1950s, the downward adjustment of real piece rates coupled with a slight increase in custom rates made widespread use of mechanical harvesters still unprofitable, except in California and Arizona where piece rates had exceeded custom rates in the late 1940s.

[11] The use of custom rates as a measure of the cost of machine harvesting is discussed in Section IV.

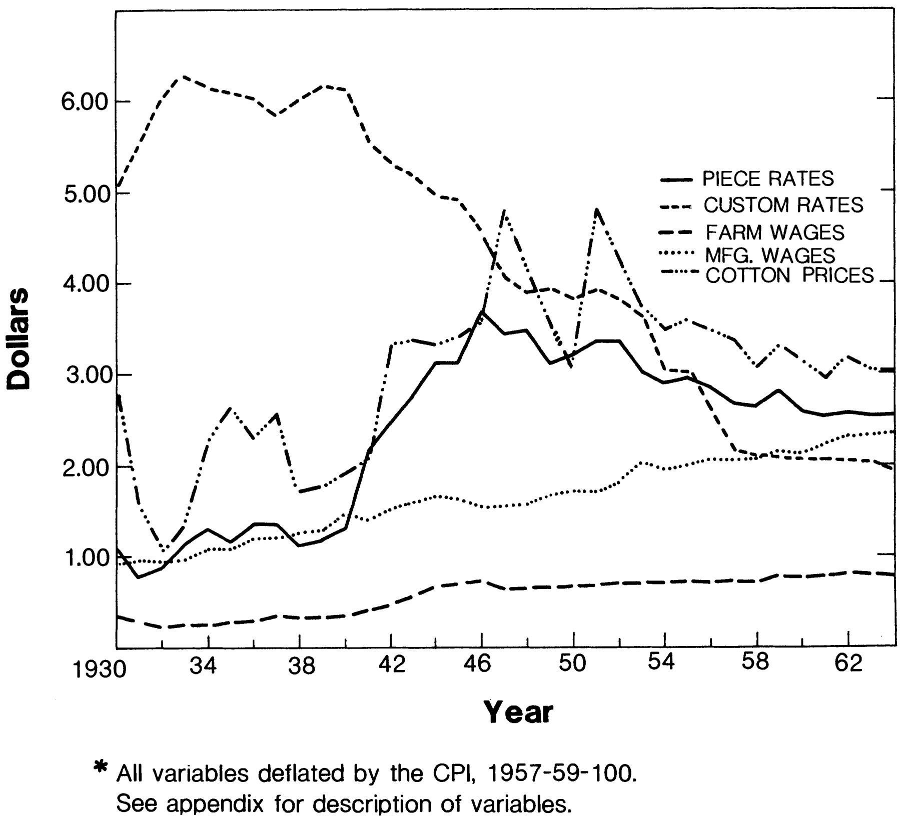

FIGURE 1
REAL WAGES AND PRICES

Notes: All variables deflated by the CPI, 1957–1959 = 100. See Appendix for description of variables and their dimensions.

As shown in Table 1 the mechanization of the cotton harvest began in the late 1940s, spreading from California and Arizona eastward to the cotton-growing areas of the South. By 1972 all of the cotton grown in the United States was harvested by machine—picked, stripped, or scraped.[12]

The substantial differences among states in the percent of cotton harvested by machine during the early part of the adoption period can be attributed to environmental and economic factors. The extensive, level fields of California and Arizona together with relatively high yields, dry weather during the harvest season, and a small weed problem lowered the cost of machine harvesting and hastened its

[12] According to the published data, the United States achieved a 100 percent mechanical harvest before the state of Mississippi. No doubt this is due to rounding. Mississippi was one of the last states to be 100 percent mechanized in the harvest of cotton.

TABLE 1
PERCENT OF COTTON HARVESTED MECHANICALLY, 12 MAJOR COTTON-PRODUCING STATES

State	1949	1954	1959	1964	1969
Alabama	*	2	6	55	88
Arizona	4	44	62	97	100
Arkansas	1	16	36	75	96
California	13	62	83	97	100
Georgia	*	3	4	62	90
Louisiana	*	28	50	78	97
Mississippi	4	11	38	68	94
Missouri	2	22	47	83	99
New Mexico	3	10	50	85	98
North Carolina	*	3	5	59	94
South Carolina	1	4	1	63	91
Tennessee	*	1	8	56	92
United States	6	22	43	78	96

* Less than 0.5 percent.
Source: USDA, Economic Research Service, *Statistical Bulletin* No. 535, "Statistics on Cotton and Related Data, 1920–73" (Washington, D.C., 1974), p. 218.

adoption in these states (Table 2).[13] Also piece rates for hand picking of cotton averaged somewhat more in the West than in the South, further contributing to the mechanization in the former states (Table 3). As shown by Tables 2 and 3 piece rates for hand picking exceeded custom rates for machine harvesting during the entire 1949 to 1964 period in California and Arizona. For the second group of states (Arkansas, Missouri, New Mexico, and Tennessee) custom rates did not fall below piece rates until 1954. For the third group custom rates did not become cheaper than piece rates until 1957. The same is true for Louisana. Consequently, the pattern of adoption of mechanical harvesting, starting in the West and moving east and south, is consistent with differences in the relative prices of the two modes of harvest.

The dramatic change from hand to mechanized harvest of cotton which swept the Cotton Belt during the 1950s and 1960s may give the impression that cotton producers were eager to switch to the new technology as fast as it became available, shunning the services of family, hired labor, and tenant farmers that for generations had brought in the cotton harvest. The scenerio of thousands of farm people being forced off the land because of the introduction of new machines is the one envisioned by the Rust brothers in the early 1930s, popularized by John Steinbeck in *Grapes of Wrath*, and is a view commonly held today.

A careful reading of the record suggests, however, that at least in the

[13] Moses S. Musoke and Alan L. Olmstead, "The Rise of the Cotton Industry in California: A Comparative Perspective," this JOURNAL, 42 (June 1982), pp. 385–412; Frank H. Maier, "An Economic Analysis of Adoption of the Mechanical Cotton Picker," (Ph.D. diss., University of Chicago, 1969).

TABLE 2
CUSTOM RATES FOR MACHINE HARVESTING OF COTTON, TWICE OVER COVERAGE
(dollars per hundredweight, current year prices)

Year	Far West	Mid South	Deep South	Louisiana
1949	$2.50	$3.00	$3.80	$3.50
1950	2.25	3.00	3.75	3.40
1951	2.50	3.30	4.15	3.80
1952	2.50	3.30	4.15	3.80
1953	2.50	3.30	4.15	3.80
1954	2.00	2.65	3.30	3.00
1955	2.00	2.65	3.30	3.00
1956	1.75	2.30	2.90	2.65
1957	1.50	2.00	2.50	2.30
1958	1.50	2.00	2.50	2.30
1959	1.50	2.00	2.50	2.30
1960	1.50	2.00	2.50	2.30
1961	1.50	2.00	2.50	2.30
1962	1.50	2.00	2.50	2.30
1963	1.50	2.00	2.50	2.30
1964	1.50	2.00	2.50	2.30

Notes: Far West is Arizona and California. Mid South is Arkansas, Missouri, New Mexico, and Tennessee. Deep South is Alabama, Georgia, Mississippi, North Carolina, and South Carolina.
Source: See Appendix for construction of data.

case of cotton harvesting, farmers were not so eager to reduce their dependence on labor. As Pederson and Rapier report in 1954:

> There is still considerable hesitancy in the matter of using machines. The mechanical picker can operate well only when the ground is dry, when weeds and grass are under

TABLE 3
PIECE RATES FOR HAND PICKING OF SEED COTTON, SEASON AVERAGE
(dollars per hundredweight, current year prices)

Year	Far West	Mid South	Deep South	Louisiana
1949	$2.93	$2.60	$2.28	$2.50
1950	3.28	2.76	2.54	2.60
1951	3.40	2.83	2.93	3.05
1952	3.48	3.18	3.04	2.95
1953	3.00	2.85	2.89	2.75
1954	3.05	2.88	2.64	2.50
1955	3.20	2.93	2.76	2.65
1956	3.15	2.80	2.79	2.65
1957	3.18	2.73	2.66	2.60
1958	3.25	2.78	2.66	2.50
1659	3.23	2.96	2.89	2.65
1960	3.23	2.81	2.86	2.60
1961	3.25	2.76	2.82	2.60
1962	3.25	2.85	2.82	2.60
1963	3.30	2.89	2.83	2.60
1964	3.35	2.91	2.85	2.50

Notes: Far West is Arizona and California. Mid South is Arkansas, Missouri, New Mexico, and Tennessee. Deep South is Alabama, Georgia, Mississippi, North Carolina, and South Carolina.
Source: USDA, Economic Research Service, *Statistical Bulletin* No. 535, "Statistics on Cotton and Related Data; 1920–73" (1974) p. 86.

control, when cotton is defoliated, and when fields are long and regular enough. The planter is torn between conflicting objectives and irreconcilable operating alternatives. Time and again planters have remarked, "If the kind of labor we had twenty years ago were available today they could keep all their machinery."

The increasing scarcity of labor in the area has raised the labor cost from a dollar a day less than fifteen years ago to four dollars and more. True the latter is an inflated dollar compared to the former but the rate of inflation is not 400 percent. Even at this higher rate the planter frequently finds himself unable to obtain labor enough to perform the essential operations during the peak work period.[14]

During World War II and the years immediately following, one of the major problems faced by farmers was the increasing scarcity of labor and the large increase in wage rates relative to prewar years. Cotton farmers were particularly affected because traditionally cotton had been a labor-intensive crop. As an illustration of the concern of farmers with obtaining adequate labor at harvest and of their reluctance to use machines, it is reported that during the 1950 harvest season in the coastal plain of South Carolina between 75 and 100 plantation operators purchased new mechanical harvesters at about $8,000 per machine but let them stand idle in their sheds while they harvested their cotton using hired labor.[15] The plantation operators considered the interest and depreciation expense on the machines as an insurance premium against not being able to obtain labor. The Korean War had just begun and the producers remembered the difficulties of finding labor during World War II. In addition to the higher cost of machines over labor in the South during the early 1950s, cotton producers preferred labor over machine harvest because the cotton was cleaner and therefore fetched a higher price in the market. Also if the producers did not hire labor to harvest they were less likely to obtain labor for weeding and thinning earlier in the season because their employees would seek jobs that allowed them to work more weeks per year.

IV

To measure the relative proportions of labor push and labor pull we construct and empirically estimate an econometric model of the cotton-picking labor market. We define labor push as a decline in the demand for labor resulting from a decrease in the price of a substitute machine (Figure 2A). Labor pull is defined as a decrease in the supply of labor due to higher wages in alternative occupations (Figure 2B).

We propose the following two-equation model to estimate the relative

[14] Harald A. Pedersen and Arthur F. Rapier, "The Cotton Plantation in Transition," Mississippi State College Agricultural Experiment Station Bulletin 508 (Jan. 1954), pp. 3–4.

[15] James H. Street, "The 'Labor Vacuum' and Cotton Mechanization," *Journal of Farm Economics*, 35 (Aug. 1953), pp. 381–97.

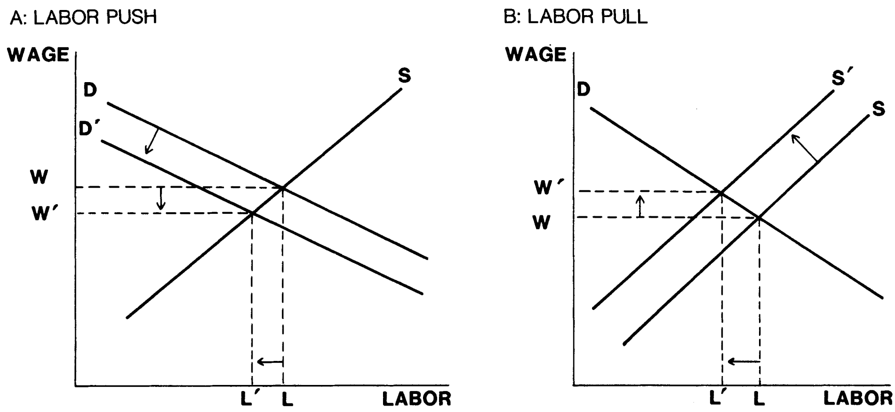

FIGURE 2
LABOR PUSH VERSUS LABOR PULL

importance of the push and pull effects on wages and employment in the cotton fields.

$$Q = \alpha_0 + \alpha_{-1}Q_{-1} + \alpha_1 P + \alpha_2 C + \alpha_3 PCT + SD + \mu \qquad \text{Demand} \quad (1)$$

$$Q = \beta_0 + \beta_{-1}Q_{-1} + \beta_1 P + \beta_2 M + \beta_3 Y + SD + v \qquad \text{Supply} \quad (2)$$

where:

Q = quantity of labor demanded, or supplied, for hand picking of cotton
Q_{-1} = Q lagged one year
P = piece rate for hand picking of cotton
C = custom rate for machine picking of cotton
PCT = price of cotton
M = hourly wage rate for production workers in manufacturing
Y = yield of cotton
SD = state dummies and their coefficients

A detailed description of the variables and data sources is presented in the Appendix. A few explanatory comments are offered here. Variables Q and P are taken as endogenous; the others are considered exogenous. Data on quantity of labor employed in hand picking of cotton do not exist. Consequently, we used the quantity of cotton harvested by hand as a proxy for the quantity of labor. All monetary variables are deflated by the Consumer Price Index (1957 to 1959 = 100) and the equations are estimated in double-log form.

The demand for labor is hypothesized to be determined by the cost of labor, the cost of machines, and the price of cotton. The cost of labor is measured as piece rates for hand picking of cotton. The cost of machines is more difficult to measure. A commonly-used technique for measuring machine costs is to synthetically construct such figures. However, machine costs estimated this way are heavily influenced by the underlying assumptions regarding the length and pattern of depreciation, number of days utilized each year, capacity of the machines, and repair costs. A more subtle problem arises because of quality improvements affecting machine characteristics such as capacity, durability, and operator comfort. Because higher-quality machines are more productive, but generally carry higher price tags, the real cost of providing a machine service can decrease even if the machine's inflation corrected price is increasing over time. Another problem, more specific to the mechanical cotton harvester, is that the cost of harvesting varies across areas having different field conditions, even though the purchase price of the machine may be relatively uniform among states. Smaller fields, lower yields, more rainy days during harvest, and a greater weed problem in the South than in the West increased the per hundredweight cost of harvest in the South compared with the West. In addition, the special features of the income-tax code including investment credit and accelerated depreciation lowered the after-tax cost of the machine but are difficult to estimate from synthetic data. Finally, reductions in harvest costs due to new varieties and to better defoliants which facilitated machine harvest are not easily accounted for in constructing machine-cost data.

Because of the above difficulties we utilized the average annual custom rate paid for machine harvesting of cotton in each state as our measure of machine cost. These are market-determined figures which reflect cost differences among states and over time stemming from differences in machine quality, environmental conditions, the income-tax law, and cotton yields. The main difficulty with using custom rates is the data problem. There is no comprehensive series of custom rates by states, over time. However, some data from various state sources do exist.

For the 1949 to 1964 period the most complete data were obtained from Arizona. A few rates for several other states were obtained from various sources (see Appendix), and the series was completed by assuming a fixed relationship to Arizona rates over time. When state figures were not available, we assumed them to be equal to other states with similar yields and growing conditions as shown in Table 2. Because there was no established market for machine harvesting of cotton prior to the late 1940s, we must ask, what custom rates for mechanical cotton picking would have been had there been a market for this service. One way to estimate these rates would be to simply extrapolate the 1949 custom rates back to 1930 by multiplying these figures by the USDA index of prices paid by farmers for machinery, 1949 = 1.00. However, as we argued earlier in the paper, the increase in the official USDA prices-paid index for farm machinery likely overstates the true, quality adjusted prices for machinery services because of quality improvements in the machines. Custom rates should be a more accurate measure of the prices of these services.

Information is available on custom rates for combine harvesting of wheat for the late 1920s and early 1950s.[16] In nominal terms these figures increased much less than the official USDA machinery prices-paid index between 1930 and 1949. In real terms custom rates for combine harvesting of wheat declined over this period whereas the real USDA price index for machines increased. The difference between the two measures is likely to be due to quality improvements in machines. It is not unreasonable to assume that quality improvements in grain combines were not significantly different from quality improvements in cotton harvesters. Both machines evolved from pull-type implements in the late 1920s to self-propelled units in the early 1950s. Also improvements in mechanical technology affecting gears, bearings, chains, and hydraulics were applicable to both machines. Because the grain combine utilized the threshing technology of the earlier stationary threshing machine, improvements during the 1930 to 1949 period in the mechanical cotton harvester were probably somewhat greater than those of the grain combine. Use of custom rates for combine harvesting of wheat, rather than the official USDA machinery price index, should provide a more accurate estimate of the true value of cotton harvesting rates. However, because the information on wheat harvesting costs is also incomplete, we utilized the two series in combination in the following way. For 1930 we assumed that the ratio of 1949 to 1930 custom rates were the same for cotton as for wheat. For the intervening years custom rates in cotton were assumed to change proportionally to the change in the USDA machine-price index.

On the supply side of the cotton-picking labor market, the explanatory variables are piece rates, alternative off-farm earnings opportunities, and cotton yields. National average wages in manufacturing are used as the measure of off-farm wages. Granted, not all field hands who left agriculture found jobs in manufacturing, but in a reasonably well-functioning labor market manufacturing wages should be closely correlated with wages in other unskilled and semiskilled occupations over time. Because the price of labor is quoted on a per-unit of cotton rather than per-unit of time basis, cotton yields are included in the labor-supply equation to take account of any change in labor supply which might occur when yields change. For example, higher yields should allow cotton pickers to increase their daily earnings given the piece rate and should therefore bring forth a greater supply of labor than when yields are lower.

The data set is a pooled time-series and cross-section for 12 of the major cotton-producing states encompassing the 1930 to 1964 period

[16] L. A. Reynoldson, et al., "The Combined Harvest-Thresher in the Great Plains," USDA *Technical Bulletin* No. 70 (Feb. 1928), p. 35; H. J. Friesen, et al., "1952–53 Custom Rates for Farm Operations in Central Kansas," *Kansas Agricultural Economic Report* No. 59 (1953), p. 14.

(420 observations).[17] The observations begin in 1930 because the post-World War II machines utilized the basic spindle technology developed by the Rust brothers in the late 1920s. Working models of these machines existed in the early 1930s.[18] Also the International Harvester Company continued to develop and produce working models of spindle-type harvesters throughout the 1920s, 1930s, and 1940s, but relatively few were sold.[19] The observations end in 1964, the last year data on piece rates for hand picking were collected; 75 percent of the cotton for these 12 states was harvested mechanically (picked, stripped, or scraped) in 1964.

The demand and supply equations were estimated simultaneously using two-stage least squares, corrected for serial correlation using the Cochrane-Orcutt iterative technique in conjunction with the Fair procedure for reducing the bias due to the inclusion of a lagged endogenous variable.[20] The model is one of partial equilibrium focusing on the price and quantity of labor for hand picking of cotton. In principle, the cost of harvesting cotton will affect the supply of the product, which in turn will affect the price and quantity of cotton produced. However during the period under consideration the effects on the price of cotton due to changes in harvest technology are likely to have been small relative to the effects of large changes in the demand for the product resulting from the Great Depression, World War II, and the increased use of synthetic fibers in the manufacture of tires and clothing after World War II.

V

The results of estimating the labor demand and supply equations by two-stage least squares are presented in Table 4. All continuous variables are in log form, and the coefficients are short-run elasticities. Long-run elasticities are calculated by dividing the corresponding coefficients by $(1 - \alpha_{-1})$ and $(1 - \beta_{-1})$ and are shown in the second column.

The elasticities reported in Table 4 are used to compute the changes in piece rates and the quantity of labor for hand picking of cotton by the shifts in the demand for and supply of this labor. The first step is to solve for the equilibrium values of the endogenous variables as shown in

[17] The 12 states are Alabama, Arizona, Arkansas, California, Georgia, Louisiana, Mississippi, Missouri, New Mexico, North Carolina, South Carolina, and Tennessee. Texas and Oklahoma were omitted because of the prevalence of strippers in these states.

[18] James H. Street, "Cotton Mechanization and Economic Development," *American Economic Review*, 45 (Sept. 1955), pp. 566–83.

[19] C. R. Hagen, "Twenty-Five Years of Cotton Picker Development," *Agricultural Engineering* 32 (Nov. 1951), pp. 593–99.

[20] Ray C. Fair, "The Estimation of Simultaneous Equation Models With Lagged Endogenous Variables and First Order Serially Correlated Errors," *Econometrica*, 38 (May 1970), pp. 507–16.

TABLE 4
ESTIMATED COEFFICIENTS OF THE STRUCTURAL MODEL, EQUATIONS 1 AND 2

	Demand			Supply		
Variables	Coefficient	Estimated	Long Run	Coefficient	Estimated	Long Run
Lagged Q (Q_{-1})	α_{-1}	0.807		β_{-1}	0.401	
		(20.7)			(5.23)	
Piece rates (P)	α_1	−0.628	−3.25	β_1	1.28	2.14
		(−5.92)			(9.28)	
Custom rates (C)	α_2	0.243	1.26			
		(5.20)				
Cotton prices (PCT)	α_3	0.969	5.02			
		(8.52)				
Manufacturing wages (W)				β_2	−2.51	−4.19
					(−14.1)	
Yields (Y)				β_3	0.790	1.32
					(10.4)	
Rho		−0.080			0.625	
		(−1.63)			(15.9)	
Durbin-Watson statistic		2.01			2.06	

Notes: Number of observations = 420; *t*-statistics are given in parentheses. "Long Run" is defined in the text. Estimating technique is simultaneous equations. 2SLS corrected for serial correlation; see text. Other variables included: state dummies.

the reduced form equations 3 and 4. (The lagged dependent variable, Q_{-1}, and the state dummies are omitted from the reduced forms to simplify the equations.)

$$P = \frac{1}{\alpha_1 - \beta_1}(\beta_0 + \beta_2 M + \beta_3 Y - \alpha_0 - \alpha_2 C - \alpha_3 PCT) \qquad (3)$$

$$Q = \frac{\alpha_1}{\alpha_1 - \beta_1}(\beta_0 + \beta_2 M + \beta_3 Y) - \frac{\beta_1}{\alpha_1 - \beta_1}(\alpha_0 + \alpha_2 C + \alpha_3 PCT) \quad (4)$$

Equations 3 and 4 are used to compute the calculated effects of changes in custom rates and manufacturing wages on piece rates and the quantity of labor. The calculations simulate average annual rates of change for the observed period (see Table 5). For example, over the sample period, 1930 to 1964, real custom rates in cotton harvesting declined at an average annual rate of 3.77 percent (column 1). To obtain the annual horizontal shift in the labor-demand equation due to changes in custom rates we solve for the time change of the reduced form equation 3:

$$(\dot{P}/P)_c = \frac{1}{\alpha_1 - \beta_1}[-\alpha(\dot{C}/C)] \qquad (5)$$

(The subscript c indicates that the solution is for the partial effect of the piece rate of custom rate changes only.) The result (−0.480) is shown in

TABLE 5
SIMULATED CHANGES
(percent per year)

	Exogenous	Endogenous		
	Change in Variable (1)	Change in Piece Rates (2)	Change in Labor (3)	Share Explained (4)
Custom rates	−3.77	−0.480	−0.614	21%
Wages in manufacturing	2.73	3.59	−2.25	79
Total			−2.86	100%

Notes
Column 1: Annual rate of change; the value of r estimated in the regression $\log x(t) = a + rt + sd + u$ for each variable x; sd is the set of state dummy variables and their coefficients.
Column 2: Column 1 times its corresponding elasticity in Table 4 times $1/(\alpha_1 - \beta_1)$. Endogenous rates are simulated. (See, for example, equation 5.)
Column 3: Column 2 times the corresponding elasticity of supply for demand shifts and the corresponding elasticity of demand for supply shifts. (See equation 6.)
Column 4: Column 3 divided by −2.86.

column 2 of Table 5. The same procedure is used to obtain the annual percent decrease in the labor-supply function and the consequent increase in piece rates due to the increase in manufacturing wages. (Calculations using the long-run coefficients are not shown in Table 5 because they yield the same relative price and quantity changes.)

We are mainly interested in the impact of the changes in custom rates and manufacturing wages on the equilibrium quantity of labor. The decrease in the demand for labor caused by the decline in custom rates decreases piece rates and the quantity of labor supplied. The calculated decrease in quantity supplied is obtained by multiplying the annual percentage change in price (piece rates) by the supply elasticity, as shown by equation 6.

$$(\dot{Q}/Q)_c = \beta_1(\dot{P}/P)_c \tag{6}$$

The result (−0.614) is shown in column 3 of Table 5. Similarly, the decrease in quantity of labor demanded due to the decrease in supply (the latter caused by the increase in manufacturing wages) is determined by multiplying the resulting annual increase in piece rates times the corresponding demand elasticity for labor ($3.59 \times -0.628 = -2.25$). Both demand and supply shifts decrease the quantity of labor exchanged in the market, thus the effects on quantity are cumulative.

According to the results shown in column 3 of Table 5, about 21 percent of the total decrease in hand picking labor is due to the decrease in demand caused by mechanization (−0.614/−2.86). The remaining 79 percent is accounted for by the decrease in supply caused by higher wages in off-farm occupations. Thus the pull effect on labor supply is much more important than the push effect in explaining the decline in labor employed in picking cotton over the period studied.

VI

The evidence presented is consistent with the hypothesis that cotton harvesting labor was in large part pulled out of agriculture by higher wages in nonfarm occupations rather than displaced by the mechanical cotton picker. While it would be inappropriate to generalize these results to all of agriculture, the cotton harvester is by no means a special case of labor pull. The results should at least prompt one to question the popular assumption that farm people have been "tractored off of farms," in effect losing their jobs to machines.

The study also highlights the close relationship between the agricultural and nonagricultural labor markets in a setting of economic growth. As wages increase in nonfarm occupations and farm workers leave to take advantage of better earnings opportunities off the farm, the remaining farmers have no choice but to mechanize jobs such as hand picking of cotton where the hourly marginal revenue product of labor falls below its opportunity cost. Farm machinery companies along with state agricultural experiment stations respond to the increased demand by farmers for new mechanical technology by developing such technology. For the most part, the change in the structure of agriculture toward larger and more mechanized farms is part of the process of economic growth that increases the price of labor relative to that of machinery services.[21]

Appendix

DEFINITIONS AND CONSTRUCTION OF VARIABLES

Quantity of labor: There are no data on days of labor devoted to picking cotton. We, therefore, measured labor as bales of cotton picked by hand and obtained the measure by multiplying total bales of cotton harvested in each state by the proportion picked by hand.
Piece rates: Prices paid by farmers in each of the 12 states to pick 100 pounds of seed cotton.
Price of cotton: Price received by farmers in each of the 12 states. In Figure 1 the price is quoted per 10 pounds to make the size of the figures compatible with the scale of the vertical axis. In the regression, cotton price is lagged one year.
Cotton yields: Pounds of cotton per harvested acre in each of the 12 states.
Custom rates: Prices paid by farmers to machine pick 100 pounds of seed cotton, twice over coverage.
Manufacturing wages: National average hourly earnings of production workers. In the regression they are lagged one year.
Farm wages: In Figure 1 the national average daily rate is divided by 10 to approximate an hourly wage.

[21] Yoav Kislev and Willis Peterson, "Prices, Technology, and Farm Size," *Journal of Political Economy*, 90 (Nov. 1982), pp. 578–95.

DATA SOURCES

Machine prices paid by farmers: For USDA index see U.S. Department of Agriculture, *Agricultural Statistics* (Washington, D.C., 1952), p. 684 and 1967, p. 564.
Manufacturing wages: U.S. Government Printing Office, *Economic Report of the President* (Washington, D.C., 1969), p. 261.
Farm wages: U.S. Department of Agriculture, *Farm Labor* (Washington, D.C., respective years).
Custom rates, 1930–1948: For sources of custom rates for combine harvesting of wheat, see fn. 16.
Custom rates, 1949–1964:
Arizona: *Arizona Agriculture*, Arizona Agricultural Experiment Station (Tucson, respective years).
Arkansas: Billy V. Lessley and James H. White, "Crop Enterprises on Cotton Farms in Southeast Arkansas," Arkansas Agricultural Experiment Station Report Series No. 111 (Fayetteville, June 1962), p. 8.
Georgia: James C. Fortson, "Break-even Points for Harvesting Machines," Georgia Agricultural Experiment Station Bulletin No. 66 (Athens, Dec. 1959), p. 78.
Louisana: Lonnie L. Fields and Suresh R. Landhe, "Farm Planning Guides for Small Farms," Louisiana Department of Agricultural Economic Report No. 350 (Baton Rouge, Jan. 1966), p. 92–93.
Mississippi: Morris M. Lindsey, "An Economic Analysis of Custom Work on Farms in the Yazoo-Mississippi Delta," Mississippi Agricultural Experiment Station Bulletin No. 667 (State College, June 1963), p. 9.
Data for other cotton variables are from U.S. Department of Agriculture, "Statistics on Cotton and Related Data," *Statistical Bulletin* 535 (Washington, D.C., 1974).