MEASURING AND EXPLAINING THE DECLINE IN U.S. COTTON PRODUCTIVITY GROWTH

Stephen C. Cooke and W. Burt Sundquist

Abstract

Tornquist input quantity indices were used to derive total and partial factor productivity measures for U.S. cotton across time, region, and scale. Total factor productivity for U.S. cotton increased .2 percent per year between 1974 and 1982. Partial productivity measures revealed that yield growth was about .6 percent and input use grew about .4 percent per year. Cotton enterprises in Alabama and Mississippi gained and those in the Texas High Plains lost competitive advantage relative to California. In 1982, very large (1750-5900 acres) and large (950-1749 acres) cotton enterprises were 2 percent more productive than medium-size enterprises (570-949 acres).

Key words: cotton, productivity, competitive advantage, scale economies, indices, enterprise budgets

THE PROBLEM: A QUESTION OF U.S. COTTON PRODUCTIVITY GROWTH

A prolonged decline in U.S. cotton productivity growth, if such were to occur, could have far-reaching consequences. Firch and others have voiced their concern on this topic since the 1970s (pp. 892-898). As competitive advantage decreased, U.S. producers would be undersold on world markets. The income of U.S. cotton producers, their input suppliers, and the rural communities in cotton regions would decrease. Although U.S. cotton consumers could partially avoid higher prices by importing lower-priced cotton, increased cotton imports would affect adversely the U.S. balance of payments. Ultimately, a decline in cotton productivity would lead to a restructuring as resources shifted out of cotton production and into other sectors of the economy. The value of many assets specialized to cotton production would be significantly reduced in the restructuring process.

This is not to say that U.S. cotton productivity actually is actually known to be declining. Unfortunately, the literature on this question is contradictory and confusing. U.S. cotton yields were reported to have declined during the 1960s and 1970s. Starbird and Hazera found that

> ... By the early 1970's, it became obvious that per acre yields of cotton were no longer increasing as expected.... A 5-year average of yields centered on 1965 and on 1979 indicates that yields have declined over that period, dropping from 504 pounds during the earlier 5-year period to 490 pounds during the latter...This trend analysis indicates that cotton yields of cotton and other major crops have leveled off since the mid-1960's in most cotton-producing states (pp. 15, 17, & 21).

Meredith too identified that cotton yields increased from 1937 to 1960 and then decreased for the next 20 years even as inputs increased (p. 33).

Declining cotton yields in the U.S. between 1960 and 1980 indicate that the productivity growth was also decreasing, unless input quantities were decreasing even faster. Meredith, just quoted, stated that inputs were actually increasing, in which case U.S. cotton productivity losses were greater than the declining yields alone would suggest. On the other hand, Thirtle reported that U.S. cotton productivity gains were over 5 percent per year between 1939 and 1978 (p. 38). Nor could Thirtle find any evidence for a "productivity growth slowdown" in cotton between 1939 and 1978. In fact, he stated that mechanical productivity gains increased in cotton between 1955 and 1978. "In cotton, the only discernible change was the increased rate of mechanical TC [technical change] from the mid-1950s onwards..." (pp. 39-40).

After 1980, several studies found U.S. cotton yields to be no longer decreasing. According to McKinion et al.,

> starting in 1981, average yields in the U.S. appeared to show an upward trend, probably due to a small decrease in ozone levels and better insect control in certain areas of the cotton belt (p. 155).

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Meredith concurred, finding yield increased in both Mississippi and California (p. 34).

This upward trend in yields, however, reportedly bypassed the Texas High Plains, where, Masud et al. concluded in 1985, an infestation of bollworms that began in 1975 "... could seriously affect the comparative economic position of cotton in this region" (p. 124). But even on this point there is disagreement. Meredith concluded that between 1965 and 1985 "decreasing inputs of irrigation and fertilizer were the major contributors to the [Texas High] Plains yield decline" (p. 35).

What, then, has actually happened to U.S. cotton productivity? And how extensive are differentials in productivity change between regions?

The objective in this paper was to document and quantify changes that occurred in U.S. cotton productivity between 1974 and 1982 as well as to search for the causes of the changes. The effects of differential productivity gains on interregional competitive advantage and the exploitation of scale economies were also examined. This was accomplished by deriving a set of total and partial productivity indices for representative U.S. cotton enterprises. In particular, total factor productivity indices were derived to measure technological change, regional competitive advantage, and scale economies in U.S. cotton production.[1] Partial productivity indices, embedded in the total indices, were used to provide insight into the sources of the productivity changes.

Methodologically, the analysis applied a second-order Taylor series expansion to a non-homothetic production function in order to estimate Tornquist's "ideal" input index. The difference between a yield index and a Tornquist input index is a total factor productivity index. The factors of the Tornquist input index represent partial productivity indices, which can be used to determine the sources of changes in productivity growth. This analysis is related by methodology to the works of Ball, Cooke, and Sundquist, and Hazilla and Kopp.

The data for this study came from 45 custom-built cotton-enterprise budgets. Enterprise budgets were constructed for each of three time periods in five cotton-producing regions and for three sizes of enterprises ($3_t \times 5_r \times 3_u = 45_{tru}$). The three crop years selected were 1974, 1978, and 1982. The five cotton regions and their selected cultural practices and FEDS[2] area designation were: northern Alabama-dryland (FEDS area 600), southcentral California-irrigated (FEDS area 500), the Mississippi Delta-dryland (FEDS area 100), and the Texas High Plains-irrigated and -dryland (FEDS area 200). California, Mississippi, and Texas were selected because of their economic importance in cotton production. Alabama was selected to provide additional diversity to the set of production systems studied. Within each region, production units were subdivided into three size categories: very large, large, and medium. Data on cotton yields, expenditures, and input quantities disaggregated on the basis of time, region, and enterprise size were used to generate productivity indices.

THE MODEL: DERIVING THE TORNQUIST "IDEAL" INPUT-QUANTITY INDEX TO DETERMINE AN INDEX OF PRODUCTIVITY

An index of total factor productivity was derived based, in part, on the Tornquist "ideal" and "exact" input-quantity index. Consider a continuous, twice-differentiable non-homothetic quadratic production function in which output is a function of input quantities and discrete variables for time, region, and size of enterprise.

(1) $Y_{tru} = f(X_{itru}, D_{tru}), \quad i = (K, L, E, F, M, A)$.

Where Y_{tru} is the yield of cotton in bales per planted acre in time t, region r, and enterprise size u; X_{itru} is quantity of input i per planted acre in time t, region r, and size u; i includes the "KLEFMA" input categories of capital (K), labor (L), energy (E), fertilizer (F), materials (M), and planted acres (A);[3] and D_{tru} is a single discrete variable representing, for simplicity, the three discrete variables of time T, region R, and enterprise size U. All inputs within input categories are considered complements; input categories themselves may be either complements or substitutes; and all input categories are variable. The presence of only one output precludes the problem of separability.

[1] The confounding effect of technological change with differences in regional resource endowments and changing scale economies is well known in the literature (Chan and Mountain; Cooke and Sundquist; Griliches; Ray; Thirtle; USDA, 1980). The importance of the "intermingled index number problem" lies in the fact that only after this sorting-out process can productivity indices be accurately determined for intertemporal, interregional, and interenterprise productivity.

[2] FEDS is the U.S. Department of Agriculture's farm enterprise data system, which includes sets of contiguous intrastate counties by homogeneous soil type and rainfall. It is these sets of intrastate counties that were referred to as "regions." The Texas 200 study area is considered as two regions, i.e., Texas-irrigated and Texas-dryland.

[3] The units for the KLEFMA inputs are service-hours/planted acre (K), hours/planted acre (L), gallons/planted acre (E), pounds/planted acre (F), weighted average units/planted acre (M), and planted/harvested acres (A).

Equation (1) can be transformed into a polynomial by means of a second-order Taylor-series expansion around points X_{io} and D_o. Dropping the r and u subscripts for simplicity of presentation, then:

$$(2)\quad Y_1 = Y_0 + \Sigma_i f'(X_{i0})(X_{il}-X_{i0}) + \Sigma_i \tfrac{1}{2} f''(X_{i0})(X_{il}-X_{i0})^2 + f'(D_0)(D_1-D_0) + \tfrac{1}{2} f''(D_0)(D_1-D_0)^2$$

where

$$f'(X_{i0}) = \frac{\delta Y_0}{\delta X_{i0}} \equiv S_{i0},$$

$$f''(X_{i0}) = \frac{\delta^2 Y_0}{\delta X_{io}^2} = \frac{\delta S_{i0}}{\delta X_{i0}},$$

$$f'(D_0) = \frac{\delta Y_0}{\delta D_0} \equiv \alpha_0,$$

$$f''(D_0) = \frac{\delta^2 Y_0}{\delta D_0^2} = \frac{\delta \alpha_0}{\delta D_0}.$$

Equation (2) can be rewritten as:

$$(3)\quad Y_1 - Y_0 = \Sigma_i S_{i0}(X_{il}-X_{i0}) + \Sigma_i \tfrac{1}{2}\left(\frac{\delta S_{i0}}{\delta X_{i0}}\right)(X_{il}-X_{i0})^2 + \alpha_0(D_1-D_0) + \tfrac{1}{2}\left(\frac{\delta \alpha_0}{\delta D_0}\right)(D_1-D_0)^2$$

where

$\delta S_{i0} = S_{i0} - S_{il}$, $\delta X_{i0} = -(X_{il} - X_{i0})$,
$\delta\alpha_0 = \alpha_0 - \alpha_1$, and $\delta D_0 = -(D_1 - D_0)$.

In turn, equation (3) can be rewritten as:

$$(4)\quad Y_1 - Y_0 = \Sigma_i S_{i0}(X_{il}-X_{i0}) - \Sigma_i \tfrac{1}{2}\left(\frac{(S_{i0}-S_{il})}{(X_{il}-X_{i0})}\right)(X_{il}-X_{i0})^2 + \alpha_0(D_1-D_0) - \tfrac{1}{2}\left(\frac{(\alpha_0-\alpha_1)}{(D_1-D_0)}\right)(D_1-D_0)^2.$$

Simplifying equation (4) results in an expression for the change in yield in terms of the changes in input quantities and changes in productivity:

$$(5)\quad Y_1 - Y_0 = \Sigma_i \tfrac{1}{2}(S_{i0}+S_{il})(X_{il}-X_{i0}) + \tfrac{1}{2}(\alpha_0+\alpha_1)(D_1-D_0).$$

If the expression for changing productivity were zero, i.e., $\tfrac{1}{2}(\alpha_0+\alpha_1)(D_1-D_0) = 0$, then equation (5) would reduce to Diewert's quadratic approximation lemma expressed in terms of a quadratic production function (p. 118).

Equation (5) can be rewritten as a productivity measure, such that:

$$(6)\quad \tfrac{1}{2}(\alpha_0+\alpha_1)(D_1-D_0) = Y_1 - Y_0 - \Sigma_i \tfrac{1}{2}(S_{i0}+S_{il})(X_{il}-X_{i0})$$

Now assume a transcendental logarithmic form of production function, such that:

$$(7)\quad \ln Y_t = f(\ln X_{it}, T).$$

Also assume that a given region and enterprise size are chosen and held constant such that their effects on the change in productivity equal zero. This makes it possible to measure only the change in productivity through time for a given region r and enterprise size u. Similar assumptions can be made to measure the isolated effects of regional resource endowment or enterprise size on productivity.

Equation (6) can be rewritten in terms of the logarithmic production function described in equation (7) as:

$$(8)\quad \tfrac{1}{2}(\alpha_{t0}+\alpha_{t1})(T_1-T_0) = \ln\left(\frac{Y_{1t}}{Y_{0t}}\right) - \Sigma_i \tfrac{1}{2}(S_{i0t}+S_{i1t})\ln\left(\frac{X_{i1t}}{X_{i0t}}\right).$$

The expression for input quantities $\left(\Sigma_i \tfrac{1}{2}(S_{i0t}+S_{i1t})\ln\left(\frac{X_{i1t}}{X_{i0t}}\right)\right)$ is the Tornquist "ideal" and "exact" input index in logs. This index is ideal in the sense that any difference between it and the yield index can be attributed to productivity increases (Diewert, p. 120). The index is exact in that it reflects a second-order approximation of a non-homothetic production function.[4]

The assumption of a logarithmic functional form does not put any *a priori* constraints on the shape of the production function. The logarithmic form, however, makes it possible to determine a second-order approximation of the production function from observable data without using econometrics:

$$(9)\quad S_{io} = \frac{\delta \ln Y_0}{\delta \ln X_{i0}} = \frac{(\delta Y_0 / Y_0)}{(\delta X_{i0} / X_{i0})} = (\delta Y_0 / \delta X_{i0})(X_{i0} / Y_0) = (P_{i0} / P_{y0})(X_{i0} / Y_0) = \frac{P_{i0} X_{i0}}{P_{y0} Y_0} = \frac{P_{i0} X_{i0}}{\Sigma_i P_{i0} X_{i0}}.$$

Equation (9) is an application of Hotelling's lemma (pp. 71-74), in which the first derivative of a logarithmic production function equals the factor share of total expenditures. Total revenue equals total expenditures under Euler's theorem assuming constant

[4] "We have obtained two families of superlative price and quantity indexes. ... Each of these index numbers is exact for a homogeneous aggregator function, which is capable of providing a second-order approximation to an arbitrary twice-continuously-differentiable aggregator function" (Diewert, p. 136).

returns to scale, in this case, within enterprise size categories.

The Tornquist index measures the change in input quantities when output changes from a point on an initial expansion path to a point on a subsequent expansion path due to changing relative input prices. In particular, the average of the initial and subsequent factor shares weights the changes in input quantities to account for changes in factor prices. If there was no change in technology between the initial and subsequent time periods, all changes in yield would be explained by the change in factor prices and the associated input substitution (including factor bias) and output effects that have taken place:

$$100e^{\frac{1}{2}(\alpha t0 + \alpha t1)(T1 - T0)} = 100\left(\left(\frac{Y_{1t}}{Y_{0t}}\right) \div \Pi_i \left(\frac{X_{i1t}}{X_{i0t}}\right)^{\frac{1}{2}(Si1t + Si0t)}\right). \tag{10}$$

Equation (10) is the index of total factor productivity derived from the antilog of equation (8) multiplied by 100. This productivity index equals the ratio of the yield index to the Tornquist input-quantity index.

Table 1 introduces a case study of how equations (8), (9), and (10) were used to calculate a change in productivity. The data for this case come from representative budgets for very large California cotton

Table 1. Deriving the Tornquist Input Quantity and Yield Indices Needed to Determine an Intertemporal Productivity Index for Very Large California Cotton Enterprises between 1974 and 1982 (1974 = 100)

			Inputs						
Row	Item	Unit	Capital	Labor	Energy	Fert.	Materials	Land	Total
Cost									
1.	CA VL 1982	($/acre)	99.48	91.36	24.48	39.97	396.40	371.57	1023.26
2.	CA VL 1974	($/acre)	54.53	38.41	6.84	41.15	204.38	73.18	418.49
Cost Share									
3.	CA VL 1982	(%)	.10	.09	.02	.04	.39	.36	1.00
4.	CA VL 1974	(%)	.13	.09	.02	.10	.49	.17	1.00
5.	$1/2\ (S_{82} + S_{74})$	(%)	.11	.09	.02	.07	.44	.27	1.00
Inputs & Input Indices									
6.	CA VL 1982	(units/acre)[a]	13.46	16.98	22.46	141.44	6.64	1.01	
7.	CA VL 1974	(units/acre)	19.62	14.55	19.45	193.56	5.81	1.01	
8.	$Ln(X_{82} / X_{74})$	(input ratio)	-0.38	0.15	0.14	-0.31	0.13	0.00	
9.	$1/2(S_{82} + S_{74})Ln(X_{82}/X_{74})$[b]		-0.04	0.01	0.00	-0.02	0.06	0.00	0.01
10.	$100(X_{82}/X_{74})^{1/2(S_{82}+S_{74})}$[c]		96	101	100	98	106	100	101
Yield & Yield Index									
11.	CA VL 1979-85 (ave bales/acre)								2.23
12.	CA VL 1972-76 (ave bales/acre)								2.09
13.	$Ln(Y_{82}/Y_{74})$ (yield index in logs)								0.06
14.	$100(Y_{82}/Y_{74})$ (yield index)								106
Productivity Index									
15.	$\frac{1}{2}(\alpha_{82} + \alpha_{74})(T_{82} - T_{74})$	(productivity index in logs)							.05
16.	$100e^{\frac{1}{2}(\alpha 82 + \alpha 74)(T82 - T74)}$	(productivity index)							105
17.	$100\left(e^{\frac{1}{2}(\alpha 82 + \alpha 74)(T82 - T74)}\right)^{1/t}$	(annual productivity index)							100.6

[a] The units of measure for the KLEFMA inputs are service hours/planted acre (K); hours/planted acre (L); gallons/planted acre (E); pounds/planted acre (F); weighted average units/planted acre (M); and planted acres/harvested acre (A).

[b] Partial and Tornquist input quantity indices in logs.

[c] Partial and Tornquist input quantity indices.

enterprises in 1974 and 1982. The Tornquist ideal index of the change in inputs, measured by the expression $(\Sigma_i \frac{1}{2} (S_{i1ru} + S_{i0ru}) \ln(X_{i1ru} / X_{i0ru}))$, appears as the last element on the right in row 9 of Table 1. Theoretically, the Tornquist ideal input index plus the change in productivity is exactly equal to the index of the change in output, measured as $(\ln(Y_{1ru}/Y_{0ru}))$ and presented in row 13. Any difference between the yield and input indices can be attributed to a shift in the production function and is measured as an index of the change in productivity over time (row 15), between regions, and/or across size categories, depending on the configuration of the data. [5]

This index of total factor productivity can also be used to determine the source(s) of a change in productivity. This is important information because, as Griliches stated, " ... it does not further our understanding of growth to label the unexplained residual changes in output as 'technical change'" (p. 331). Fortunately, the total productivity factor indices of technical change, regional competitive advantage, and economies of scale can be explained in terms of their yield index and the factors of the input quantity index defined above. The yield index equals the change in yield (row 14 in Table 1, expressed in base 10). The input quantity index equals the product of factor share weighted changes in the KLEFMA inputs (row 10, in base 10).

Thus, the factors of the total factor productivity index embody partial factor productivity indices. The partial productivity index of input i in base 10 is $100e^{\frac{1}{2}(Sil + Si0) \ln (Xil/Xi0)}$, or $100(X_{il} / X_{i0})^{\frac{1}{2}(Sil+Si0)}$. [6] For example, in Table 1, the partial productivity index for capital appears as the first element in row 10. These partial productivity indices measure the source and contribution of the embodied quality differences in the KLEFMA inputs either to reduce input quantity or to increase yield, independent of changes in relative prices (Griliches, fn 11, p. 334). These differences in turn are associated with technological progress, regional resource endowment or scale economies. For example, the information in row 14 of Table 1 shows that yield increased 6 percent between 1974 and 1982. If there were no productivity gains and if each input increased proportionately (as it would for a linearly homogeneous function), then the factor-share-weighted quantity of each input would have to increase by 1 percent as well. Using the 101 standard of comparison (sixth root of 1.06 x 100), [7] we see that the productivity gains for very large cotton enterprises in California between 1974 and 1982 originated from a decrease in the need for capital (96 percent - 101 percent = -5 percent), fertilizer (-3 percent), energy (-1 percent), and land (-1 percent) inputs (see row 10, Table 1). These productivity gains were twice as large as the productivity loss from an increased need for materials (5 percent). The relative contribution of labor did not change. This accounts for all of the 5 percent total factor productivity gain in cotton for these enterprises over the eight-year period (line 16), or an annual compounded productivity gain of .6 percent (eighth root of 1.05 x 100) (line 17). [8]

A methodology is thus provided to measure the growth in cotton productivity as indices of total factor productivity that also encompass measures of the sources of growth through the embodied partial productivity indices by input category.

THE DATA: 45 COTTON ENTERPRISE BUDGETS AND YIELDS

The primary data on input quantities and expenditures for representative cotton enterprises used in the analysis come from cost-of-production surveys conducted by USDA as part of its Firm Enterprise Data System (FEDS). The three FEDS surveys for cotton used in this study were conducted for the 1974, 1978, and 1982 production years. The five regions selected for analysis were defined above. The data acquired from the FEDS surveys were used to construct a total of 45 representative enterprise budgets (3 years x 5 regions x 3 size categories), which were used in the analysis. A 1984 version of the USDA/ERS budget generator was used to translate capital stocks into annual flows of prices and quantities. [9] All inputs

[5] It was assumed that scale economies within size categories were constant.

[6] The partial productivity indices are additive in base e and multiplicative in base 10.

[7] If there were no productivity gains, each KLEFMA category would be expected to increase about 1 percent for a product of 6 percent, which would just equal the 6 percent change in yield. Therefore, in this case, the standard increase in input use, against which the actual change in input use was compared, was 101 percent. The standard of comparison was found by taking the 6th root of the yield ratio and multiplying by 100. The 6th root came from the six KLEFMA input categories that had been multiplied together to determine the input index.

[8] The annual compounded rate of intertemporal productivity gain was determined by taking the nth root of the productivity gain (n is the number of years the total productivity gains accrued). The intertemporal productivity indices are presented as annual compounded rates rather than totals.

were grouped into one of the six input categories of capital, labor, energy, fertilizer, materials, and acres of land (KLEFMA). These data were augmented by yield data from other USDA and Census of Agriculture sources.

The enterprise size classifications were made on the basis of planted acres reported in the FEDS surveys for each region and year, arrayed from largest to smallest. The very large size class was defined as those enterprises with planted acres within the 100th to 91st percentiles. The large enterprise size class included the 90th to 71st percentiles, and the medium size class was defined as those enterprises falling within the 70th to 41st percentiles. The survey data within each size class were used to build a synthetic "representative" enterprise budget for that size category, region, and year. The same percentiles were used to define size categories for each of the three years studied. The small size class (40th to 1st percentiles of planted acres) of cotton enterprises included so much variation in size and production technology as to defy the identification of representative enterprises, thus precluding any valid approximation of per unit production costs. Hence the small enterprise size class was omitted for this study.

Table 2 reports the average size of very large, large, and medium size cotton enterprises on a planted-acres basis for each of the five cotton production systems in 1974, 1978, and 1982. A weighted-average size for each production-system in each year is presented also.[10] The table clearly shows that the average size of cotton enterprises increased dramatically in all five production regions between 1974 and 1982.[11]

Table 3 shows the number of enterprises and the percent of U.S. production in the five sample pro-

Table 2. Average Size of Cotton Enterprise by Production Region (Planted Acres)

Year	Size Category	Region: Alabama Area 600 (No. Cent)	California[a] Area 500 (So. Cent.)	Mississppi Area 100 (Delta)	Texas[a] Area 200 (Hi. Plains)	Texas Area 200 (Hi Plains)	Weighted Average[b]
		Acres					
1982	V. Large	1842	2833	2868	1707	5920	3048
	Large	917	1432	1202	929	1825	1336
	Medium	568	614	754	436	972	656
	Weighted Ave.[c]	1180	1768	1379	1018	2906	1707
1978	V. Large	1006	2847	3133	1786	3228	2643
	Large	675	1593	1277	601	963	1179
	Medium	471	830	557	357	510	611
	Weighted Ave.[c]	679	2261	1135	843	1567	1578
1974	V.Large	673	1335	751	583	1063	969
	Large	258	655	453	310	485	490
	Medium	126	375	310	174	213	280
	Weighted Ave.[c]	387	862	652	378	570	642

[a] Irrigated.

[b] Weights for average enterprise size across regions and within size categories were based on 1979-85, 1976-80, and 1972-76 average county-level USDA/SRS data and were determined by the ratio of a region's production to the sum of production across regions.

[9] The assumptions within the budget generator program were at the discretion of the researchers. The key assumption was that all tractors and machinery were fully utilized. Care was taken to make sure that harvesting machinery was fully utilized for a given enterprise size.

[10] Weights used in calculation of weighted averages by size were developed from U.S. Census of Agriculture data.

[11] Since the sampling objective of the two FEDS surveys was to provide an equal probability of inclusion for any specific acre of cotton in the sample area, larger farms were sampled at a higher rate than smaller ones. Thus, after 1974, the enterprise data presented in Table 2 came from a sampling frame that was skewed in favor of the larger cotton enterprises in the production region surveyed.

duction regions in 1982. Average cotton yields for 1982, 1978, and 1974 are presented also. In order to minimize the effects of year-to-year weather variability on cotton productivity, five-year yield averages for 1974 and 1978 and a seven-year yield average for 1982 were used. Cotton yields vary widely from year to year and lack a strong trend (Starbird and Hazera, p. 17). Average cotton yields for all regions taken together were about 8 percent less in 1978 than in 1974. By 1982, the average cotton total yield had rebounded to about 8.5 percent above its 1974 level. These figures are consistent with the observations cited earlier of Starbird and Hazera and of McKinion et al., regarding the decline and subsequent improvement in cotton yields nationally. Actually, closer examination of Table 3 reveals that cotton yields recovered after 1974 in all regions except the Texas High Plains.

In sum, data on input quantities, expenditures, and yields, disaggregated on the bases of time, region, and enterprise size, were used to generate productivity indices for a set of 45 representative cotton enterprises. Total and partial productivity indices were estimated using a second-order Taylor-series expansion of a non-homothetic quadratic translog production function. These results are presented in Tables 4 through 10 and discussed below.

THE RESULTS

Intertemporal Productivity Changes

Table 4 shows intertemporal productivity changes for the 30 cotton enterprises ($3_u \times 5_r \times 2_t$) between 1974 and 1982 and between 1974 and 1978. The annual change in U.S. cotton productivity was about +.2 percent between 1974 and 1982 and -5 percent between 1974 and 1978. If 1978 is compared to 1982, annual productivity change would be 5.6 percent. One implication of this is the importance of endpoints and what they imply about the causes of change in annual gains.

Table 3. Number of Enterprises, Share of Production, and Yields of Sample Regions for Cotton

		Region					
		Alabama Area 600 (No. Cent)	California[a] Area 500 (So. Cent.)	Mississippi Area 100 (Delta)	Texas[a] Area 200 (Hi. Plains)	Texas Area 200 (Hi. Plains)	Total or Average
No. of enterprises in 1982		220	560	400	950	500	2,630
Share of 1982 production[b]		1.70	22.60	7.98	9.88	7.43	49.60
Year	Size Category	bales/acre					
1982	Very Large[c]	1.33	2.23	1.57	0.69	0.46	1.30
	Large[c]	1.28	2.23	1.57	0.71	0.46	1.30
	Medium[c]	1.28	2.06	1.53	0.70	0.47	1.25
	Weighted Ave.[d]	1.30	2.18	1.55	0.70	0.46	1.28
1978	Very Large[c]	0.86	1.93	1.13	0.74	0.44	1.09
	Large[c]	0.90	1.92	1.13	0.75	0.45	1.10
	Medium[c]	0.83	1.84	1.11	0.78	0.47	1.09
	Weighted Ave.[d]	0.86	1.91	1.11	0.76	0.45	1.09
1974	Very Large[c]	0.90	2.09	1.07	0.82	0.61	1.19
	Large[c]	0.85	2.09	1.05	0.80	0.60	1.18
	Medium[c]	0.80	2.04	1.05	0.78	0.58	1.15
	Weighted Ave.[d]	0.86	2.08	1.06	0.80	0.60	1.18

[a] Irrigated.

[b] USDA/SRS data tapes on county-level production 1979-1985 and USDA/ERS Ag. Info. Bull. No. 476 "Cotton: Background for 1985 Farm Legislation," Appendix Table 7 on U.S. aggregate production 1979-1983.

[c] 1974, 1978, and 1982 Census of Agriculture Table 41 "Specified Crops by Harvested Acres" data were used to determine the ratio of very large, large, and medium size yields to state-wide averages. This ratio was multiplied by the FEDS region multiple-year average yield from USDA/SRS data to obtain yield by size for the region.

[d] USDA/SRS data tapes on county-level planted acres and production for 1972-1976, 1976-1980, and 1979-1985.

Table 4. Intertemporal Productivity Indices for Cotton in the U.S. in 1982 and 1978 (1974 = 100)[a]

Year	Size Category	Region: Alabama Area 600	California[b] Area 500	Mississippi Area 100	Texas[b] Area 200	Texas Area 200	Weighted Average
1982	V. Large	131	105	151	74	86	102
	Large	164	111	147	78	61	102
	Medium	180	102	151	80	64	100
	Weighted Ave.	154	107	150	77	70	102
	Annual Change (%)	6	1	5	-3	-4	0.2
1978	V. Large	106	82	114	74	77	85
	Large	129	86	132	62	55	82
	Medium	119	81	103	81	59	81
	Weighted Ave.	120	83	110	71	63	82
	Annual Change (%)	5	-5	2	-8	-11	-5

[a] Because the index was computed relative to the 1974=100 base, numbers greater than 100 indicate the extent to which enterprises were more productive in 1982 and 1978 than in 1974, and conversely for numbers less than 100.

[b] Irrigated.

Sources of Intertemporal Productivity Changes

Intertemporal partial factor productivity indices are presented in Tables 5 and 6. These tables represent a decomposition of the weighted average total factor productivity indices from Table 4 by region and scale, respectively. Analysis of the indices for the individual KLEFMA input categories and average yield reveals the individual contributions to total factor productivity during the 1974 to 1982 period.

(1) Capital: Between 1974 and 1982, requirements for capital inputs fell for all representative cotton enterprises across all regions and size categories, for an average annual reduction of about .6 percent per acre (eighth root of .95 - 1). More than anything else, this reduction probably reflects the increasing size and power of machinery and equipment, which resulted in fewer service-hours per acre required to accomplish the various tillage, planting, cultivation, and harvesting operations. The largest reductions in annual capital inputs (about 1 percent) occurred in Alabama and California.

(2) Labor: Between 1974 and 1982, labor requirements also fell across all regions and sizes, for an average annual reduction of about .4 percent per acre. These modest decreases in labor inputs complement the reductions in capital inputs.

(3) Energy: The consumption of fuel per acre did not change significantly on most representative enterprises over the 1974 to 1982 period. This implies that fuel consumption per service-hour of capital actually increased since capital inputs decreased while the fuel requirement remained the same. Furthermore, energy may have been reallocated to different uses within enterprises. Within irrigated enterprises with lowering water tables, for example, more fuel may have been used for pumping water in 1982 than in 1974.

(4) Fertilizer: Requirements for fertilizer fell slightly between 1974 and 1982 on all representative cotton enterprises, for an average annual reduction of .1 percent per acre.

(5) Materials: Inputs of materials increased by an average annual rate of 1.4 percent on all representative enterprises between 1974 and 1982. Increases in pesticide use were the most common contributor to increased materials cost shares. Increased material requirements were most pronounced (1.7 to 2.4 percent per year) on cotton enterprises on the Texas High Plains due to the infestation of bollworms mentioned earlier.

(6) Land: The ratio of planted acres to harvested acres remained approximately constant between 1974 and 1982.

(7) Total Inputs: Between 1974 and 1982 the total quantity of inputs required for cotton production increased by about .4 percent per acre per year. Overall, the 1.5 percent increase in the use of materials more than offset the 1.1 percent decrease in the use of capital, labor, and fertilizer.

The reduction in capital and labor requirements associated with quality improvements in machinery is consistent in direction, if not in scope, with Griliches' findings that these inputs were the "main sources" of productivity gain in U.S. agriculture between 1940 and 1960 (p. 332). However, as will be shown, capital and labor improvements represented only modest sources of productivity gains in

Table 5. Intertemporal Partial and Total Productivity Indices for Cotton in the U.S. by Region in 1982 and 1978 (1974 = 100)[a]

		Region					
Year	Input	Alabama Area 600	California[b] Area 500	Mississippi Area 100	Texas[b] Area 200	Texas Area 200	Overall Average
1982	Capital	92	92	95	98	98	95
	Labor	98	99	97	95	95	97
	Energy	101	100	101	101	102	101
	Fertilizer	100	99	100	98	100	99
	Materials	109	110	105	124	117	113
	Land	100	100	99	100	101	100
	Total Inputs	99	98	98	113	112	103
	Yield	152	105	146	87	78	105
	Productivity	154	107	150	77	70	102
1978	Capital	91	96	94	115	98	99
	Labor	98	100	99	99	99	99
	Energy	100	100	100	101	101	100
	Fertilizer	99	99	99	99	97	99
	Materials	97	117	104	117	126	115
	Land	101	100	100	100	100	100
	Total Inputs	85	111	96	132	120	113
	Yield	103	92	105	95	76	92
	Productivity	120	83	110	71	63	82

[a]Because the total productivity indices were computed relative to the 1974 = 100 base, numbers greater than 100 indicate the extent to which enterprises were more productive than in 1974, and conversely for numbers less than 100. For the partial productivity indices, numbers greater than 100 indicate the extent to which input use and yields were greater than in 1974, and conversely for numbers less than 100.

[b]Irrigated.

Table 6. Intertemporal Partial and Total Productivity Indices for Cotton in the U.S. by Enterprise Size in 1982 and 1978 (1974 = 100)[a]

	1982			1978		
Input	V. Large	Large	Medium	V. Large	Large	Medium
Capital	96	93	95	97	99	99
Labor	98	96	97	99	99	99
Energy	100	101	101	100	100	100
Fertilizer	98	100	100	98	99	100
Materials	111	116	112	112	116	116
Land	100	100	100	100	100	100
Total Inputs	101	104	104	107	114	115
Yield	104	106	104	91	92	93
T. Productivity	102	102	100	85	82	81

[a] Because the total productivity indices were computed relative to the 1974 = 100 base, numbers greater than 100 indicate the extent to which enterprises were more productive than in 1974, and conversely for numbers less than 100. For the partial productivity indices, numbers greater than 100 indicate the extent to which input use and yields were greater than in 1974, and conversely for numbers less than 100.

cotton production over the 1974 to 1982 period compared to their contribution historically. We would expect this to continue to hold true after 1982 as well.

(8) Yield: On average, between 1974 and 1982, yields increased about .6 percent per year, or just slightly more than the .4 percent per year increase in inputs.

(9) Total Factor Productivity: The net result of the increase in yields and the slightly smaller increase in inputs was a modest annual increase in total factor productivity for cotton of about .2 percent over the eight-year time span. Furthermore, as Table 6 shows, even these modest productivity gains were not distributed uniformly across enterprise sizes. In particular, the average medium-size cotton enterprises achieved no productivity gains between 1974 and 1982.

Thirtle reported an annual productivity gain of 5.2 percent for cotton between 1939 and 1978. He disaggregated this into an annual "biological" gain of .5 percent and an annual "mechanical" gain of 4.7 percent (p. 38).[12] Yield indices such as the one above can be thought of as an approximation of biological productivity gains. Thus, Thirtle's .5 percent annual biological productivity gain is identical to the .5 percent annual increase in yield found in this study. However, Thirtle's 4.7 percent mechanical gain is about five times greater than the 1 percent per year gain from capital and labor savings found in this study. (Thirtle did not include a separate "materials" input category in his study).

Given labor's meager share of total inputs in current production systems (about 10 percent), it is reasonable to assume that the large increases in labor-saving productivity gains observed and reported by Thirtle over the 39 years from 1939 to 1978 make similar gains in the future highly unlikely. Therefore, the more relevant comparison between Thirtle's study and this one is of his biological gains and our measure of overall productivity gains. From this perspective, our eight-year average annual productivity gain for cotton of .2 percent is consistent with, or slightly lower than, Thirtle's 39-year annual biological gain of .5 percent.

Between 1974 and 1978, productivity declined by about 4.8 percent per year (Table 5 and 6). This period appears to have been a time when cotton producers were caught in a double bind. First, the large mechanical productivity gains that had been achieved earlier had come to an end. At the same time, yields actually decreased due, in part, to growing losses from pests, while expenditures on pesticide increased (Meredith, p. 35). Between 1978 and 1982, the reversals of the 1974 and 1978 period were themselves reversed. Total input use decreased about 2.3 percent per year, while yield increased about 3.3 percent per year for an average annual total factor productivity gain of about 5.6 percent compared to the .2 percent annual gain from 1974 to 1982. The 5.6 percent productivity gain compares much more closely to Thirtle's 5.2 percent. However, the contribution of mechanical gains was only 1.5 percent per year while "biological" gains were an unprecedented 3.3 percent per year.

The large difference in total factor productivity changes between 1978 and 1982 and between 1974 and 1982 reflects the amalgamation of two events. First, between 1974 and 1978, yields in Texas decreased dramatically (1-6 percent per year). The decline in yields in the Texas High Plains can be explained, in part, by an infestation of bollworms that began after 1975 (Masud et al. p. 117). Second, between 1978 and 1982, yields in Alabama and Mississippi increased dramatically (6 to 8 percent per year) due to the use of earlier maturing varieties such as DES 119, more effective control of bollworms, and the suspension of production on marginal acreage.[13] Meredith observed a significant "curvilinear" increase in Mississippi cotton yields after 1981 (p. 34).

These results are a particularly telling example of endpoint effects on the measure of cotton productivity. Schultz has shown that the choice of endpoints can make a considerable difference in measurements of productivity (pp. 108-109). In this case, once mechanization had taken place, mechanical productivity gains reached a plateau. This plateau appears to have been reached for U.S. cotton between 1974 and 1982. However, Thirtle argues that this mechanical-technology plateau had not been reached for cotton by 1978 (p. 39). In fact he suggested that mechanical productivity gains in U.S. cotton could be expected to continue at the level achieved in the 1950s (p. 40). As a result, one should study carefully the causes of stability or instability in productivity changes, including analyzing the changes in partial

[12] Thirtle defined "biological" technical change as "the shifting of the land/fertilizer isoquant toward the origin" (p. 35). "Mechanical" technical change was defined as "the shift in the labor/machinery isoquant" (p. 35). This approach was based on Hayami and Ruttan's" yield-raising biological/chemical and labor-saving mechanical technical change dichotomy (p. 35).

[13] These reasons for improved cotton yields in the Mississippi Delta came from James Hamill, cotton specialist, Mississippi State University (telephone conversation).

productivity indices, before undertaking policy or management responses for cotton production.

The productivity gains in cotton between 1974 and 1982 were low on average in all five regions studied compared to Thirtle's results. However, there was considerable variability among regions. Such differences in intertemporal productivity would be expected, over time, to have the effect of shifting regional competitive advantage from less to more productive regions. Thus, the competitive positions of Alabama and Mississippi should have improved between 1974 and 1982, while that of the Texas region, both dryland and irrigated, declined.

Regional Productivity and the Sources of Competitive Advantage

Of the five cotton regions studied, California was the most productive cotton region (see Table 7). This was true at the time of all three FEDS surveys. Over the 1974 to 1982 period, California was between 10 and 29 percent more productive than its next closest competitor. However, there are indications that California cotton yields were lower than expected, in part, because of increases in ozone and sulfur dioxide concentrations (Meredith, p. 35).

Mississippi ranked third in cotton productivity in 1974, but had advanced to second in both 1978 and 1982. Mississippi was only 10 percent less productive than California in 1978 and 1982, the result of narrowing an earlier 35 percentage-point productivity gap. Alabama ranked fourth in cotton productivity in 1974 and third in both 1978 and 1982. Alabama was 10 to 19 percent less productive than Mississippi in cotton production over the 1974 to 1982 time period.

The improving competitive positions of Alabama and Mississippi can be attributed to improved yields, which increased 19 and 21 percentage points while total inputs only increased 10 and 4 percentage points, respectively, between 1974 and 1982 (see Table 8). In 1974, cotton yields in Mississippi and Alabama were about 40 to 50 percent of yields in California. By 1982, cotton yields increased in Mississippi and Alabama to about 60 to 70 percent of those in California.

In contrast, Texas-dryland ranked second in cotton productivity in 1974 but had fallen to fourth or fifth in 1978 and fourth in 1982. Texas-dryland cotton productivity went from being 16 percentage points more productive than Alabama in 1974, to being 35 percentage points less productive in 1982. Texas-ir-

Table 7. Interregional Productivity Indices for Cotton in 1982, 1978, and 1974 (California = 100)[a]

		Region				
Year	Size Category	Alabama Area 600	Californiab Area 500	Mississippi Area 100	Texas[b] Area 200	Texas Area 200
1982	V. Large	69	100	84	33	37
	Large	68	100	77	34	33
	Medium	75	100	99	36	37
	Weighted Ave.	71	100	90	35	36
	Rank	3	1	2	5	4
1978	V. Large	77	100	82	51	47
	Large	77	100	95	40	45
	Medium	65	100	91	50	47
	Weighted Ave.	73	100	90	47	47
	Rank	3	1	2	4	4
1974	V. Large	62	100	64	55	58
	Large	54	100	68	59	83
	Medium	46	100	73	52	72
	Weighted Ave.	55	100	65	55	71
	Rank	4	1	3	4	2

[a] Because the regional productivity indices were computed relative to the California = 100 base, numbers less than 100 indicate the extent to which enterprises in California have a competitive advantage over those in other regions.

Table 8. Interregional Productivity Indices for Cotton in 1982, 1978, and 1974 (California = 100)[a]

		Region				
Year	Input	Alabama Area 600	California[b] Area 500	Mississippi Area 100	Texas[b] Area 200	Texas Area 200
1982	Capital	85	100	86	103	76
	Labor	95	100	96	96	94
	Energy	100	100	100	98	97
	Fertilizer	103	100	100	94	92
	Materials	103	100	99	101	91
	Land	100	100	100	102	104
	Total Inputs	86	100	82	94	60
	Yield	60	100	72	32	21
	Productivity	71	100	90	35	36
1978	Capital	78	100	77	108	70
	Labor	93	100	94	96	93
	Energy	100	100	100	99	99
	Fertilizer	102	100	99	94	88
	Materials	84	100	92	88	87
	Land	101	100	100	101	101
	Total Inputs	63	100	66	87	50
	Yield	46	100	60	40	24
	Productivity	73	100	90	47	47
1974	Capital	77	100	80	89	63
	Labor	95	100	97	97	93
	Energy	100	100	100	99	98
	Fertilizer	103	100	96	91	86
	Materials	100	100	104	89	82
	Land	100	100	101	101	102
	Total Inputs	76	100	78	70	41
	Yield	41	100	51	39	29
	Productivity	55	100	65	55	71

[a] Because the regional productivity indices were computed relative to the California = 100 base, numbers less than 100 indicate the extent to which enterprises in California have a competitive advantage over those in other regions. For the partial productivity indices, numbers less than 100 indicate the extent to which input use and yields in California were greater than in other regions, and conversely for numbers greater than 100.

[b] Irrigated.

rigated ranked fourth or fifth in cotton productivity in 1974 and 1978 and fifth in 1982. Texas-irrigated went from being 16 percentage points less productive than Texas-dryland in 1974, to being about equally productive in 1978 and 1982. Texas-irrigated cotton enterprises in 1982 used about 57 percent more inputs (94 percent divided by 60 percent) to obtain 52 percent more output (32 percent divided by 21 percent) relative to dryland enterprises.

The deterioration in the competitive position of the Texas High Plains cotton-producing region, both irrigated and dryland, resulted from 7 to 8 percentage point declines in yields accompanied by 24 to 19 percentage point increases in total inputs. (See Table 8.) Thus, research efforts to maintain or even improve cotton productivity in the Texas High Plains were more than offset by an adverse combination of pests and increasingly scarce and expensive water supplies. As a result, the operating and capital losses for High Plains cotton enterprises during the 1974 to 1982 period resulted in financial crises for many of the affected cotton producers.[14]

The indices of competitive advantage in Tables 7 and 8 suggest that the variability among the five regions' productivity gains had the expected effect, over time, of shifting regional competitive advantage from low productivity regions (the Texas High Plains) toward high productivity regions (Mississippi and Alabama).

Scale Economies and Their Sources

One strategy that producers can adopt to help overcome differences in regional competitive advantage and slow productivity growth is to exploit scale economies where they exist. On average, productivity changes from scale economies in cotton production ranged from 4 percent to -2 percent between 1974 and 1982 in the five regions studied (see Table 9). In general, the indices of scale economies suggest that cotton producers in the Alabama, California, Mississippi, and Texas-irrigated regions exploited scale economies and thereby improved their competitive advantage. Texas-dryland producers, however, did not exploit scale economies fully.

It could have been predicted that cotton producers on the Texas High Plains would have been especially aggressive in taking advantage of scale economies. However, from 1978 to 1982, unexploited gains from scale economies remained in the 9 percent to 11 percent range. This result is unexpected given the decline in the region's competitive advantage that had occurred. But the average size of Texas-dryland cotton enterprises was already at about 3000 acres in 1982. This was 64 percent larger than the average size of cotton enterprises in California, the region with the next largest average enterprise size. Under the circumstances of declining yields and productivity, along with an already very large average enterprise size, Texas-dryland cotton producers may have decided that the risk of enterprise expansion was greater than the potential productivity gain. In addition, financial stress may have limited further enterprise expansion options.

Table 10 reveals no consistent pattern of scale economies for all regions that can be attributed either to more efficient input use or to improved yields. Hence, it seems likely that the size adjustments that occurred between 1974 and 1982 resulted mainly from factors other than gains in technical production efficiencies, such as pecuniary economies. We would expect this to continue to be the case after 1982. Thirtle's estimate of 2 to 8 percent "pseudo increasing returns" to scale for cotton (p. 40) is double the 1 to 4 percent estimated in this study between 1978 and 1982.

WARRANTED ASSERTIONS: THE DECLINE IN THE GROWTH OF U.S. COTTON PRODUCTIVITY

The objective of the study was to document and quantify a suspected decline in U.S. cotton productivity and to search for its causes. This was done by deriving a set of total and partial productivity indices for representative U.S. cotton enterprises, from which the sources of productivity changes were determined. In particular, total factor productivity indices were derived to measure intertemporal productivity, regional competitive advantage, and

Table 9. Scale Economies Indices for Cotton in 1982, 1978, and 1974 (Very Large = 100)[a]

		Region					
Year	Size Category	Alabama Area 600	California[b] Area 500	Mississippi Area 100	Texas[b] Area 200	Texas Area 200	Average
1982	V. Large	100	100	100	100	100	100
	Large	101	102	95	104	91	99
	Medium	99	96	108	98	90	98
1978	V. Large	100	100	100	100	100	100
	Large	99	102	115	82	89	97
	Medium	77	98	100	98	90	96
1974	V. Large	100	100	100	100	100	100
	Large	80	101	98	99	130	102
	Medium	72	103	111	90	121	102

[a] Because the index was computed relative to the Very Large = 100 base, numbers greater than 100 indicate the extent to which Large and Medium size enterprises, are more productive than very large enterprises and conversely for numbers less than 100.

[b] Irrigated.

Table 10.Partial and Total Indices of Scale Economies for Cotton in 1982, 1978, and 1974 (Very Large = 100)[a]

	1982			1978			1974		
Input	V. Large	Large	Medium	V. Large	Large	Medium	V. Large	Large	Medium
Capital	100	99	100	100	102	102	100	100	100
Labor	100	99	100	100	101	101	100	100	100
Energy	100	100	100	100	100	100	100	100	100
Fertilizer	100	101	100	100	101	100	100	100	99
Materials	100	102	99	100	101	100	100	96	97
Land	100	100	100	100	100	100	100	100	100
Total Inputs	100	101	99	100	104	104	100	96	95
Yield	100	100	97	100	101	100	100	99	96
Productivity	100	99	98	100	97	96	100	102	102

[a] Because these productivity indices were computed relative to the Very Large = 100 base, numbers greater than 100 indicate the extent to which Large and Medium cotton enterprises are more productive than Very Large enterprises, conversely for numbers less than 100. For the partial productivity indices, numbers greater than 100 indicate the extent to which input use and yields were greater for Large and Medium size enterprises than for the Very Large enterprises, and conversely for numbers less than 100.

scale economies in U.S. cotton production. Partial productivity indices were derived to provide some insight into the sources of the productivity changes.

On average, between 1974 and 1982, cotton productivity increased at the relatively slow rate of about .2 percent per year across the five regions of this study, in comparison to a 5.2 percent per year increase between 1939 and 1978 reported by Thirtle. This decline in the growth of U.S. cotton productivity was due mainly to a sizeable reduction in mechanical gains, which dropped from 4.7 percent per year during the 1939 to 1978 period to 1 percent per year between 1974 and 1982. Even these reduced mechanical gains were slightly more than offset by the additional use of materials (primarily pesticides), which increased at an average rate of about 1.4 percent per year. Thus, between 1974 and 1982, annual cotton productivity gains continued to be realized due to continuing biological gains that remained positive, constant, and small at around .5 percent.

In U.S. cotton production, the 1974 to 1978 period probably coincides generally with the transition from the large mechanical gains that had been realized earlier to the beginning of primarily biological gains, vulnerable to losses from pests. By 1974, the era of large productivity gains from labor-saving mechanization in U.S. cotton production was apparently over. Subsequently, U.S. cotton productivity gains have and will in all likelihood continue to come from biological advances. Unfortunately, the record of biological gains in U.S. cotton during the last half century (a record that has been reaffirmed by this study) has been modest at best. Perhaps future gains through biotechnology will be more impressive.

Though the productivity gains over time were low, on average, in all five regions studied, there was considerable variability across regions. The indices of competitive advantage suggest that the variability in productivity gains over time had the predicted effect of shifting regional competitive advantage away from the less productive region of the Texas High Plains toward the more productive regions of Mississippi and Alabama. The improvement in the competitive advantage of Mississippi and Alabama can be traced to yield increases achieved without comparable increases in input use, while in Texas the reverse was true.

A policy implication of our results relates to cotton farmers' responsiveness to government-paid diversion incentives. Duffy et al. found that producers in the Southern Plains (New Mexico, Oklahoma, and Texas) were the most responsive to paid diversion "with an estimate of slightly more than 2 percent of acreage removed from production for each $1.00 per acre of the weighted diversion payment" (p. 106). These authors speculated that the reason for this higher responsiveness "may be explained by the low returns after cash expenses in that region relative to other regions" (p. 106). Our results on the declining competitive position of the Texas High Plains cotton provides further evidence to support this conclusion.

The indices of scale economies suggest that Alabama and Texas-irrigated cotton producers exploited scale economies between 1978 and 1982 to improve their competitive advantage. Texas-dryland producers appear not to have exploited scale economies fully. In general, however, we found no consistent pattern of scale economies that can be attributed either to more efficient input use or better yields.

The cotton productivity indices developed in this study, and the changes in them over time, are important indicators of regional and international comparative advantage in cotton production. Large differences in productivity between regions, such as the ones found in this study, are capable of forcing a restructuring of the U.S. cotton industry. In addition, the lack of significant productivity gains in any region will over time, erode the ability of cotton producers in that region to compete in world markets and will lead to increased imports of cotton and cotton products into the U.S.

One set of productivity indices alone does not contain all the information relevant to restructuring U.S. cotton production. Also of importance are such things as the alternative farm production and off-farm employment opportunities available to farmers, and the commodity-based government programs in effect. However, as the market for agricultural commodities becomes increasingly global, and in the event that reduced producer subsidies and freer trade become the norm, productivity indices can serve as an important indicator of a commodity's long-term international competitive position.

REFERENCES

Ahearn, M., R. Dudman and G. Hanson. "Financial Performance of Specialized Cotton Farms." Washington, DC: USDA ERS, Agr. Info. Bull. 58, May 1988.

Ball, V.E. "Output, Input, and Productivity Measurement in U.S. Agriculture, 1948-79." *Am. J. Agr. Econ.*, 67(1985):475-486.

Chan, M.W.L., and D.C. Mountain. "Economies of Scale and the Tornquist Discrete Measure of Productivity Growth." *Rev. Econ. and Stat.*, 65(1983):663-667.

Cooke, S.C. and W.B. Sundquist. "Cost Efficiency in U.S. Corn Production." *Am. J. Agr. Econ.*, 71(1989):1003-1010.

Diewert, W.E. "Exact and Superlative Index Numbers." *J. Econometrics, 4(1976):115-145.*

Duffy, P.A., J.W. Richardson, and M.K. Wohlgenant. "Regional Cotton Acreage Response." *So. J. Agr. Econ., 19(1987):99-109.*

Firch, R.S. "Adjustments in a Slowly Declining U.S. Cotton Production Industry." *Am. J. Agr. Econ.*, 55(1973):892-902.

Griliches, Z. "The Source of Measured Productivity Growth: United States Agriculture, 1940-1960." *J. Pol. Econ.*, 71(1963):331-346.

Hazilla, M., and R. Kopp. "Intertemporal and Interspatial Estimates of Agricultural Productivity." *Agricultural Productivity: Measurement and Explanation.* S.M. Capalbo and J.M. Antle, eds. Washington, D.C.: Resources for the Future, 1988.

Hotelling, H. "Demand Functions with Limited Budgets." *Econometrica*, 3(1935):66-78.

Masud, S.M., R.D. Lacewell, J.R. Stoll, J.K. Walker, and J. F. Leser. "Impact of a More Intensive Insect Pest Infestation Level on Cotton Production: Texas High Plains." *So. J. Agr. Econ.*, 17(1985):117-125.

McKinion, J.M., V.R. Reddy, and D.N. Baker. "Yield and Productivity Study in Cotton: Final Conclusions." *Proc. Beltwide Cotton Res. Conf., 155, 1988.*

Meredith, W.R. "Final Report of the Cotton Foundation Yield and Productivity Study." *Proc. Beltwide Cotton Res. Conf., 33-37, 1987.*

Ray, S.C. "A Translog Cost Function Analysis of U.S. Agriculture, 1937-1977." *Am. J. Agr. Econ.*, 64(1982):490-498.

Schultz, T.W. *The Economic Organization of Agriculture.* New York: McGraw-Hill Book Co., 1953.

Starbird, I.R. and J. Hazera. "Yield Trends in Cotton-Producing Regions." *Cotton and Wool Outlook & Situation.* Washington, D.C: USDA ERS, Aug. 1982.

Thirtle, C.G. "Technological Change and Productivity Slowdown in Fields Crops: United States, 1939-78." *So. J. Agr. Econ.*, 17(1985):33-42.

U.S. Department of Agriculture. "Measurements of U.S. Agricultural Productivity: A Review of Current Statistics and Proposal for Change." Washington, D.C.: National Economics Division, ESCS. Tech. Bull. 1614, Feb. 1980.

U.S. Department of Agriculture. "Cotton: Background for the 1985 Farm Legislation." Washington, D.C.: ERS. Agr. Inf. Bull. 471, Sept. 1984.

U.S. Department of Agriculture. Economic Research Service. Firm Enterprise Data System, National Survey of Producers of Agricultural Commodities. Conducted by R. Krenz and G. Garst, ERS, 1975 and 1983. Stillwater, Oklahoma, unpublished.

U.S. Department of Agriculture. *County Planted Acres, Yield and Production Data by Commodity, 1972 to 1985.* J. Breuggan, ed. Washington, D.C.: SRS/ National Agricultural Statistical Service. Available on tape.

U.S. Department of Commerce. *Census of Agriculture.* Washington, D.C.: Government Printing Office, 1974, 1978, and 1982.