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

by

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Abstract

Tornquist input quantity indexes derived from USDA/SRS/FEDS survey data along with yield data are used to derive total and partial factor productivity measures across time and region for a sample of representative U.S. cotton enterprises. Total factor productivity for U.S. cotton increased only .2% per year between 1974 and 1982 compared to a much higher post-World-War-II growth rate of about 5%. Partial productivity measures revealed that yield growth was about .6% per year, while total input use grew about .4% per year. Among the input categories, capital and labor requirements decreased about 1% per year and materials use increased by about 1.5%. Cotton enterprises in selected regions in Alabama and Mississippi gained and those in the Texas High Plains lost competitive advantage relative to enterprises in the California region.

Key Words

cotton, productivity, competitive advantage, indexes, 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 since the 1970's (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 benefit from 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 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 1960's and 1970's. After 1980, McKinion, et al. found U.S. cotton yields to be no longer decreasing.

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

Our objective in this paper is to document and quantify changes that occurred in U.S. cotton productivity between 1974 and 1982. We also examine the effects of differential productivity gains on interregional competitive advantage. We will do this by deriving a set of total productivity indexes for representative U.S. cotton enterprises. In particular, total factor productivity indexes are derived to measure technological change and regional competitive advantage in U.S. cotton production.

Methodologically, the analysis applies a second-order Taylor series expansion to a non-homothetic production function in order to estimate Tornquist's "ideal" input index. 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 forty-five, 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 x 5_r x 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[1] 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).

The Model: Deriving the Tornquist "Ideal" Input-Quantity Index to Determine an Index of Productivity

We begin by deriving an index of total factor productivity 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) $Y_{tru} = f(X_{itru}, D_{tru})$, $i=(k,l,e,f,m,a)$

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);[2] 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.

Equation (1) can be transformed into a polynomial by means of a second-order Taylor-series expansion around points X_{i0} and D_0. Dropping the r and u subscripts for simplicity of presentation, then

$$(2)\ Y_1 = Y_0 + \Sigma_i f'(X_{i0})(X_{i1}-X_{i0}) + \Sigma_i \tfrac{1}{2} f''(X_{i0})(X_{i1}-X_{i0})^2 + f'(D_0)(D_1-D_0) + \tfrac{1}{2} f''(D_0)(D_1-D_0)^2.$$

Where $f'(X_{i0}) = \delta Y_0/\delta X_{i0} \equiv S_{i0}$, $f''(X_{i0}) = \delta^2 Y_0/\delta X_{i0}{}^2 = \delta S_{i0}/\delta X_{i0}$, $f'(D_0) = \delta Y_0/\delta D_0 \equiv \alpha_0$, and $f''(D_0) = \delta^2 Y_0/\delta D0^2 = \delta\alpha_0/\delta D_0$.

Equation (2) can be rewritten as

$$(3)\ Y_1 - Y_0 = \Sigma_i S_{i0}(X_{i1}-X_{i0}) + \Sigma_i \tfrac{1}{2}(\delta S_{i0}/\delta X_{i0})(X_{i1}-X_{i0})^2 + \alpha_0(D_1-D_0) + \tfrac{1}{2}(\delta\alpha_0/\delta D_0)(D_1-D_0)^2.$$

Where $\delta S_{i0} = S_{i0} - S_{i1}$, $\delta X_{i0} = -(X_{i1} - X_{i0})$, $\delta\alpha_0 = \alpha_0 - \alpha_1$, and $\delta D_0 = -(D_1 - D_0)$.

In turn, equation (3) can be rewritten as

$$(4)\ Y_1 - Y_0 = \Sigma_i S_{i0}(X_{i1}-X_{i0}) - \Sigma_i \tfrac{1}{2}((S_{i0}-S_{i1})/(X_{i1}-X_{i0}))(X_{i1}-X_{i0})^2 + \alpha_0(D_1-D_0) - \tfrac{1}{2}((\alpha_0-\alpha_1)/(D_1-D_0))(D_1-D_0)^2.$$

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

$$(5)\ Y_1 - Y_0 = \Sigma_i \tfrac{1}{2}(S_{i0}+S_{i1})(X_{i1}- X_{i0}) + \tfrac{1}{2}(\alpha_0+\alpha_1)(D_1-D_0).$$

If the expression for changing productivity across time 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 production function (p. 118).

Rewriting equation (5) as a productivity measure results in

(6) $\frac{1}{2}(\alpha_0+\alpha_1)(D_1-D_0) = Y_1 - Y_0 - \Sigma_i\frac{1}{2}(S_{i0}+S_{i1})(X_{i1}- X_{i0})$.

Now assume a translog production function, such that

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

Assume also 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 T 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 translog production function described in equation (7):

(8) $\frac{1}{2}(\alpha_0+\alpha_1)(T_1-T_0) = \ln(Y_{1ru}/Y_{0ru})$

$- \Sigma_i\frac{1}{2}(S_{i0ru}+S_{i1ru})\ln(X_{i1ru}/X_{i0ru})$.

The expression for input quantities ($\Sigma_i\frac{1}{2}(S_{i0ru}+S_{i1ru})$ $\ln(X_{i1ru}/X_{i0ru})$) is the Tornquist "ideal" and "exact" input index. This index is ideal in the sense that any difference between it and the yield index can be attributed to productivity increases. The index is exact in that it reflects a second-order approximation of a non-homothetic production function (Diewert, p. 120). Finally, the second-order approximation of the index can be determine non-parametrically. In particluar, the first derivative of a translog production function equals the factor share (S in equation 8) by applying Hotelling's lemma (pp. 71-74).

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

By taking the antilog and multiplying both sides of equation (8) by 100, the index of total factor productivity equals the ratio of the yield index to the Tornquist input-quantity index. Thus, the yield and input indexes are, themselves, partial productivity indexes.

$$(10)\quad 100e^{\frac{1}{2}(\alpha 0+\alpha 1)(T1-T0)} = 100((Y_{1ru}/Y_{0ru})$$
$$\div \pi i(X_{i1ru}/X_{i0ru})^{\frac{1}{2}(Si1ru+Si0ru)})$$

We now have a methodology to measure the growth in cotton productivity as indexes of total and partial productivity.

The Data: 45 Cotton Enterprise Budgets and Yields

The primary data on input quantities and expenditures for representative cotton enterprises used in our 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 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 then used in our analysis. These data were augmented by yield data from other USDA and Census of Agriculture sources.

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 then used to build a synthetic "representative" enterprise budget for that size category, region, and year.

Table 1 shows the number of enterprises and the percent of U.S. production in the five sample production 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, we used 5-year yield averages for 1974 and 1978 and a 7-year yield average for 1982. Average cotton yields for all regions taken together were about 8% less in 1978 than in 1974. By 1982, the average cotton total yield had rebounded to about 8.5% above its 1974 level.

In sum, data on input quantities, expenditures and yields, disaggregated on the bases of time, region, and size were used to generate productivity indexes for a set of 45 representative cotton enterprises. Total productivity indexes were estimated using a second-order Taylor-series expansion of a non-homothetic translog production function. These results are presented in tables 2 and 3.

The Results: Intertemporal Productivity Growth

Table 2 shows intertemporal productivity changes between 1974 and 1982. Overall, the annual compounded gain in intertemporal cotton productivity was about .2% between 1974 and 1982. (The annual compounded productivity gain is determined by taking the 8th root of (102/100) -1 x 100.) The input, yield, and productivity indexes (equation 10) reveal the following:

1) Input index: Between 1974 and 1982 the total quantity of inputs required for cotton production increased by about .4% per acre per year. Overall, a 1.5% increase in the use of materials more than offset a 1.1% decrease in the use of capital, labor, and fertilizer.

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

3) Productivity index: The net result of the increase in yields and the slightly smaller increase in inputs was a very modest annual increase in total factor productivity for cotton over this eight-year time span of about .2%.

Thirtle reported an annual productivity gain of 5.2% for cotton between 1939 and 1978. He disaggregated this into an annual "biological" gain of .5% and an annual "mechanical" gain of 4.7% (p. 38).[3] Yield indexes such as the one above can be thought of as an approximation of biological productivity gains. Thus, Thirtle's .5% annual biological productivity gain is virtually identical to the .6% annual increase in yield found in this study. However, Thirtle's 4.7% mechanical gain is almost five times greater than the 1% per year gain from capital and labor savings found in this study. (Thirtle did not include a separate "materials" input category in his study.)

Thus, unfortunately, our eight-year average annual productivity gain for cotton of .2% is discouragingly consistent with Thirtle's thirty-nine-year annual biological gain of .5%. We believe it is reasonable to assume that the large increases in labor-saving productivity gains observed and reported by Thirtle over the thirty-nine years from 1939 to 1978 make similar gains in the future highly unlikely given labor's meager 10% share of total input expenditures.

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, we would predict from the results in table 2 that the competitive positions of Alabama and Mississippi improved between 1974 and 1982 while that of the Texas region, both dryland and irrigated, declined.

The Results: Interregional Competitive Advantage

Of the five cotton regions studied, California was the most productive (see table 3). This was true at the time of all three FEDS surveys. Over the 1974 to 1982 period, California was between 2 and 27% more productive than its next closest competitor. However, other research has found California cotton yields to be lower than predicted, 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 2% less productive than California in 1978, the result of narrowing an earlier 38 percentage-point productivity gap. Then the gap widened again in 1982. Alabama ranked fifth in cotton productivity in 1974 and third in both 1978 and 1982. Alabama was 7 to 23% 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 11 and 2 percentage points, respectively, between 1974 and 1982. In 1974, cotton yields in Mississippi and Alabama were about 40 to 50% of yields in California. By

1982, cotton yields had increased in Mississippi and Alabama to about 60 to 70% of those in California.

In contrast, Texas-dryland ranked second in cotton productivity in 1974 but had fallen to fourth in both 1978 and 1982. Texas-dryland cotton productivity went from being 18 percentage points above Alabama's in 1974 to being 35 percentage points below in 1982. Texas-irrigated ranked fourth in cotton production in 1974 and 1978 and fifth in 1982. Texas-irrigated went from being 17 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% more inputs (94% ÷ 60%) to obtain 52% more yield (32% ÷ 21%) 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 21 to 25 percentage point increases in total inputs. 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 (including the boll worm) 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 led to financial crises for many of the affected cotton producers.[4]

The indexes of competitive advantage in table 3 suggest that the variability among the five regions' productivity gains did have the expected effect, over time, of shifting regional competitive advantage from low productivity regions (the Texas High Plains) toward higher productivity regions (Mississippi and Alabama). California held its lead as the most competitive region.

Conclusion: Declining Growth in U.S. Cotton Productivity

Our objective 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 indexes for representative U.S. cotton enterprises, from which the sources of productivity changes were then determined. In particular, total factor productivity indexes were derived to measure intertemporal productivity and regional competitive advantage in U.S. cotton production.

On average, between 1974 and 1982, cotton productivity increased at the relatively slow rate of about .2% per year across the five regions of this study, in comparison to a 5.2% per year increase between 1939 and 1978 reported by Thirtle.

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.

Though the productivity gains over time were low, on average, in all five regions studied, there was considerable variability across regions. The indexes of competitive advantage suggest that the variability in productivity gains over time did have 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. California was able to maintain its regional competitive advantage.

One 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 lack of significant productivity gains in a region will, over time, erode the ability of U.S. cotton producers in that region to compete in world markets, leading, in turn, to increased imports of cotton and cotton products into the U.S. Of importance to cotton producers are such things as the alternative farm production and off-farm employment opportunities available, and the commodity-based government programs in effect. As the market for agricultural commodities becomes increasingly global, and in the event that reduced producer subsidies and freer trade become the norm, productivity indexes can serve as an important indicator of a commodity's long-term international competitive position.

Table 1. Enterprises, Share of Production and Yields of Sample Regions for Cotton

Cotton	State	Alabama	California[1]	Mississippi	Texas[1]	Texas	Total/
	FEDS Area	600	500	200	200	200	Average
	Location	(No.Cent)	(So.Cent.)	(Delta)	(Hi.Plains)	(Hi.Plains)	.
1982 No. of enterprises	#	220	560	400	950	500	2,630
1982 U.S. production[2]	%	1.70	22.60	7.98	9.88	7.43	49.60
1982 Enterprise size	wt ave acres	1180	1768	1379	1018	2906	1707
1982 Very Large	bales/acre	1.33	2.23	1.57	0.69	0.46	1.30
Large		1.28	2.23	1.57	0.71	0.46	1.30
Medium		1.28	2.06	1.53	0.70	0.47	1.25
Wt Ave		1.30	2.18	1.55	0.70	0.46	1.28
1974 Very Large	bales/acre	0.90	2.09	1.07	0.82	0.61	1.19
Large		0.85	2.09	1.05	0.80	0.60	1.18
Medium		0.80	2.04	1.05	0.78	0.58	1.15
Wt Ave		0.86	2.08	1.06	0.80	0.60	1.18

[1] Irrigated.

[2] Source: USDA/SRS data tapes on county-level production 1979-1985.

Table 2. Intertemporal Partial and Total Productivity Indexes for U.S. Cotton: 1982 (1974 = 100).

Cotton Indexes	Alabama Area 600	California[1] Area 500	Mississippi Area 200	Texas[1] Area 200	Texas Area 200	Over All Average	Annual Average
Capital	92	92	95	98	98	95	-0.6%
Labor	98	99	97	95	95	97	-0.4%
Energy	101	100	101	101	102	101	0.1%
Fertilizer	100	99	100	98	100	99	-0.1%
Materials	109	110	105	124	117	113	1.5%
Land	100	100	99	100	101	100	0.0%
Input	99	98	98	113	112	103	0.4%
Yield	152	105	146	87	78	105	0.6%
Productivity	154	107	150	77	70	102	0.2%
Annual Ave.	5.5%	0.8%	5.2%	-3.2%	-4.4%	0.2%	

Interpretation: Since the input, yield, and productivity indexes are computed relative to the 1974 = 100 base, index numbers greater than 100 indicate the extent to which enterprises used more inputs, have higher yields, and were more productive in 1982 than in 1974, and conversely for index numbers less than 100.

[1] Irrigated.

Table 3. Interregional Productivity Indexes for Cotton in 1982, 1978 & 1974 (California = 100).

Cotton Indexes	Alabama Area 600	California[1] Area 500	Mississippi Area 200	Texas[1] Area 200	Texas Area 200
------1982------					
Input	86	100	82	94	60
Yield	60	100	71	32	21
Productivity	70	100	87	34	35
Rank	3	1	2	5	4
------1978------					
Input	60	100	60	83	48
Yield	45	100	59	39	24
Productivity	75	100	98	48	48
Rank	3	1	2	4	4
------1974------					
Input	75	100	80	69	39
Yield	41	100	50	39	29
Productivity	55	100	62	56	73
Rank	5	1	3	4	2

Interpretation: Input, yield and productivity indexes less than the California = 100 base indicate the extent to which enterprises in California use more inputs, have higher yield and have a competitive advantage relative to those in other regions.

[1] Irrigated

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[1] 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 we refer to as "regions." We have counted the Texas 200 study area as two regions, i.e., Texas-irrigated and Texas-dryland.

[2] 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).

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

[4] Although the farm populations and data sets are not directly comparable, a high percentage of specialized cotton farms in the Southern Plains (33-37%) remained financially stressed and 39% had negative net returns in 1986 (Ahearn, et al., 1988).

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