HOW COTTON ACREAGE, YIELD, AND PRODUCTION RESPOND TO PRICE CHANGES

By Sam Evans and Thomas M. Bell*

THE QUESTION

How does an increase in the farm or support price of cotton affect its total production? This question is usually answered in two steps. First, a change in acreage harvested is estimated, and second, the acreage change is multiplied by an estimated average yield. Average yield is typically estimated by some technique such as trend, moving averages, last year's yield, and so forth.

▲ Regional upland cotton acreage and yield response equations were estimated by ordinary least squares. Cotton production response to price is shown to depend upon the relative responses of acreage to price, yield to price, and yield to acreage. Examples appear of ways the analysis may be used to help policymakers decide on price support and acreage control levels. Traditionally, percentage changes in acreage have been equated with percentage changes in production. However, it is shown that a 13-percent change in cotton acreage harvested may be required to change production by 10 percent.

▲ Keywords: Cotton, acreage and yield response, price, weather, region, elasticity, ordinary least squares.

However, Houck and Gallagher, among others, have demonstrated that some factors affecting acreage planting decisions, especially price, also significantly influence average yield. Ignoring the interdependencies between acreage and yield responses may lead to serious errors in estimating total production response (acreage times yield) to changes in key variables.

An Approach to the Solution

We present equations to explain variations in upland cotton acreages and yields in the major producing regions. These equations will be used to illustrate the intricacies of estimating total production response to economic and other variables. The results strongly suggest that analysis of yield response to economic and policy variables should be given increased attention in evaluating total production response.

Theoretical Basis

Following Houck and Gallagher, we express the production function (for cotton) as:[1]

$$Q = f(HA, I) \tag{1}$$

Cotton production is shown as a function of harvested acreage (HA) and the quantities of inputs (I), such as fertilizer, applied per acre. The acreage decisions are influenced by net returns from cotton relative to those from competing crops, Government programs, and so forth.

Suppose producers decided to plant A_o acres of cotton (harvested HA_o acres). Economic theory suggests an aggregate supply function of the form:

$$Q = g(P/PI, HA_o) \tag{2}$$

in which cotton output (Q) is a function of cotton price (P), prices of variable inputs (PI), and the land input (HA_o).

A yield per acre function can be derived from (2):

$$Y = Q/HA_o = h(P/PI, HA_o) \tag{3}$$

We expect the relation between Y and P/PI to be positive, assuming that producers seek to maximize profits. Yet we expect a negative relationship between Y and HA since increases in cotton acreage involve bringing marginal land into production. Decreases in cotton acreage will lead to a higher average yield because marginal land moves out of cotton production.

Production Response to Price

To estimate production we use a system of two behavioral equations and an identity:

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*The authors are agricultural economists with the Commodity Economics Division, ESCS.

[1] Houck, J. P. and Paul W. Gallagher. "The Price Responsiveness of U.S. Corn Yields." *American Journal of Agricultural Economics* 58, No. 4, November 1976: 731-734.

$$HA = a(P, ZA)^{2} \tag{4}$$

$$Y = y(P, HA, ZY) \tag{5}$$

and the identity is:

$$Q = HA \cdot Y \tag{6}$$

Previously undefined variables ZA and ZY embody all other factors affecting the levels of harvested acreage and average yield, respectively.

The total differentials of the system are (ignoring the Z's, for simplicity):[3]

$$dHA = a_p dP \tag{7}$$

$$dY = y_p \cdot dP + y_{HA} \cdot dHA \tag{8}$$

and

$$dQ = Y \cdot dHA + HA \cdot dY \tag{9}$$

Using Cramer's rule, we solve for $\frac{dQ}{dP}$ and find:

$$\frac{dQ}{dP} = HA \cdot y_p + HA \cdot y_{HA} \cdot a_p + Y \cdot a_p \tag{10}$$

Multiplying through by P/Q, we derive the production elasticity for price (and with some algebraic manipulations):

$$E_{Q/P} = E_{Y/P} + E_{Y/HA} \cdot E_{HA/P} + E_{HA/P}$$

$$= E_{Y/P} + E_{HA/P}(1 + E_{Y/HA}) \tag{11}$$

$E_{Q/P}$, $E_{Y/P}$, and $E_{HA/P}$ are the elasticities of production, yield, and harvested, respectively, for price. $E_{Y/HA}$ is the elasticity of yield for harvested acreage.

The response of production to price, therefore, depends upon the relative responses given above. All we know *a priori* is that $E_{Y/P}$ and $E_{HA/P}$ are positive and $E_{Y/HA}$ is negative. If $E_{Y/P}$ equals 0, $E_{Q/P}$ will always be less than $E_{HA/P}$. If $E_{Y/P}$ exceeds O, $E_{Q/P}$ may be greater or less than $E_{HA/P}$.

The implication is that policymakers, to achieve desired production increases or decreases, must be aware of the relative responses contained in expression (11). For example, if $E_{Y/HA}$ were large relative to $E_{Y/P}$, a cut in acreage of 15 percent might be required to achieve a 10-percent reduction in production. Finally, policymakers and economists need also to be cognizant of regional differences in the response of producción to changes in economic and policy variables. We now show what happens regionally to cotton production, testing our equations by changing certain economic and policy variables.

RESULTS

Cotton acreage and yield equations were estimated for four producing regions in the United States by ordinary least squares with data for 1959-76 cotton crop years and 1951-74 crop years. For significant variables, the acreage equations were virtually identical across regions. However, the yield equations differed. The basic regional yield equation expressed yield as a function of deflated cotton price, harvested acreage, rainfall and temperature variables, acreage planted in "skip-row" patterns, and a time trend to account for technological change.

Obviously, the weather variables differ because of cotton's widespread geographical area.

Trends in cotton yields were similar in the Delta and Southeast. No discernible trend was evident in the Southwest while the Western region exhibited a significant trend effect in only the early to mid-fifties. Deflated cotton price had a significant effect in the Southeast and Western yield equations, but not in the Delta and Southwest. In the Southwest, an area of relatively low cotton yields, producers apply fertilizer and other inputs less intensively than producers elsewhere. Thus, the insignificant price variable was not unexpected.

REGIONAL RESPONSES OF COTTON ACREAGE

The general form of the acreage response equations with expected signs is:[4]

$$A_i = a_0 + a_1\,PCT_i - a_2\,AVOC_i - a_3\,DIV_i$$
$$+ a_4\,DP_i + a_5\,ALOT_i + e \tag{12}$$

where:

i	=	U.S. total, or one of the four producing regions
A_i	=	planted acreage of upland cotton, thousands of acres
PCT_i	=	average farm price of upland cotton, cents per pound, January through April of current calendar year
$AVOC_i$	=	the sum of the average variable and opportunity costs of growing cotton, cents per pound

[2] Harvested acreage is expressed as a function of planted acreage (A): $HA = f(A)$, and $A = a(P, ZA)$.

[3] We thank Keith Collins, an agricultural economist with the Commodity Economics Division, ESCS, for suggesting this exposition.

[4] Evans, R. S. "Regional U.S. Cotton Acreage Response." *Cotton and Wool Situation*, CWS-11, Econ. Res. Serv., U.S. Dept. Agr., July 1977.

DIV_i = payment for diverting cotton acreage weighted by acreage eligible for diversion, cents per pound

DP_i = direct or deficiency payment for producing cotton weighted by acreage eligible for support, cents per pound

$ALOT_i$ = upland cotton acreage allotment, 1959-70, lagged acreage thereafter, thousands of acres

e = random error term

Average Variable and Opportunity Costs

The average variable and opportunity costs of producing upland cotton were calculated as follows:

$$AVOC_i = \frac{(P_i)(Y_i) - VC_i + VCC_i}{YC_i} \qquad (13)$$

Where:

i = one of four cotton production regions

P_i = expected farm price of a competing crop, January through April average of current calendar year—or announced support price, whichever is greater

Y_i = expected yield of a competing crop, per harvested acre

VC_i = expected production costs of a competing crop, dollars per harvested acre

VCC_i = expected costs of producing cotton less ginning costs, dollars per harvested acre

YC_i = expected yield of cotton lint, pounds per harvested acre

The variable, AVOC, identifies the price farmers must get for their cotton for returns above variable costs from cotton to equal those from alternative crops. The cotton acreage response curve (to cotton price) will shift to the left as AVOC increases and to the right as AVOC decreases.

Values of AVOC were calculated for the four major cotton producing regions; we assumed producers' expected yield would equal averages of the previous 3 years. Regional production cost estimates were obtained from USDA's Cost of Production Surveys for the 1974-76 crop years. Estimates for earlier years were made by adjusting the 1976 costs by USDA's "Index of Prices Paid For Production Items, Interest, Taxes, and Wage Rates."

Competing crops analyzed were: (a) soybeans in the Delta States of Arkansas, Louisiana, Mississippi, Missouri, and Tennessee; (b) corn and soybeans, equally weighted in the Southeastern region, consisting mainly of Alabama, Georgia, North Carolina, and South Carolina; (c) grain sorghum, used as cotton's chief competitor for the Southwestern States of Texas and Oklahoma; and (d) barley, used for the Western States of California, Arizona, and New Mexico.

Policy Variables

The national acreage response equation and each regional equation contain three policy variables: allotment acreages (ALOT); a diversion payment variable (DIV), and a direct payment variable (DP).

The allotment set an upper limit on acreage during the years in which marketing quotas were in effect (1959-70 in our study). However, since 1971, the allotment has served chiefly as a payment base rather than an acreage restriction. For the 1971-76 crop years, lagged acreage was used as a proxy for an upper limit.

The direct and diversion payments vary directly with the amount of the payments per pound and the acreage eligible for payments. Other things equal, cotton acreage would be expected to vary inversely for diversion payments and positively for direct payments. The equations were first estimated with direct payments as a separate variable. Because of the closeness of the coefficients on this variable and on the cotton price variable, the equations were reestimated with price and direct payments combined (except for the Delta).

The formula used to calculate the diversion and direct payment variables is given below:

$$DP \text{ or } DIV = \frac{B \cdot V}{W} \qquad (14)$$

where:

DP = weighted direct payment, cents per pound

DIV = weighted diversion payment, cents per pound

B = acreage eligible for direct or diversion payments

W = weighting factor (16.2 million acres, U.S. allotment for 1964-69 crop years)

V = payment rate, cents per pound.

Equations

Estimated cotton acreage response equations appear in table 1. Generally speaking, the signs of the estimated coefficients are consistent with prior expectations, the estimated coefficients are large relative to their standard errors, and the high R^2's indicate the model's adequacy in explaining historical variations in planted cotton acreage.[5]

COTTON YIELD RESPONSE

Cotton yields are affected by weather, and economic, cultural, technological, and environmental factors.[5]

[5] Dudley, G. E., J. R. Donald, and R. G. Barlowe. "Yield and Acreage Implications for U.S. Cotton." *Cotton Situation*, CS-247, Economic Research Service, U.S. Department of Agriculture, August 1970.

Table 1—Regressions with cotton acreage as dependent variable, 1959-76

Equation	Constant	ALOT	PCT + DP	PCT	DP	DIV	AVOC	R^2	S.E.	D.W.
Delta	2,128	0.416		91	49	−580	−90	0.89	253	2.22
t-value	(2.4)	(3.3)		(5.5)	(2.0)	(7.3)	(7.2)			
Southeast	199	0.739	32			−347	−27	0.94	169	1.86
t-value	(0.4)	(9.5)	(3.3)			(6.4)	(3.6)			
Southwest	2,915	0.499	46			−839	−46	0.96	255	2.06
t-value	(4.2)	(7.5)	(3.1)			(11.0)	(4.6)			
West	374	0.453	28			−123	−23	0.90	79	1.84
t-value	(2.6)	(5.4)	(6.2)			(5.1)	(4.5)			

Note: Variables defined in text; acreage in thousands; S.E. = standard error and D. W. = Durbin-Watson test value.

Economic Factors

Changes in prices and production costs have both positive and negative impacts on cotton yields. For example, if higher cotton prices were expected, producers would increase the use of fertilizer and other yield-boosting inputs. They would also increase acreage planted to cotton, which would affect yield adversely as inferior (cotton) land comes into production.

In the Delta region, greater cotton acreage usually means more planted in mixed or heavy soils markedly less suited for cotton than are the finer soils. In the Southwest region, increased cotton acreage is highly correlated with increased nonirrigated acreage. Cotton yields on such acreage may be 1/3 to 1/2 lower than on irrigated acreage.

Weather Variables

Weather significantly influences cotton yields. They are susceptible to drought, excessive rainfall, and temperature extremes, especially freezing temperatures in autumn. Insect damage and weather are also related; for example, warm wet weather increases the likelihood of insect damage.

No completely satisfactory method of incorporating weather variables in yield response functions has been developed to date. We attempted it as follows: Monthly rainfall and temperature observations at weather reporting stations within subregions roughly corresponding to the USDA's Crop and Livestock Reporting Districts were obtained for 1951-74. Rainfall and temperature were expressed in mean deviation form (acre inches and degrees Fahrenheit) for each phase of the cotton planting and harvesting season.[6] These data were then aggregated to the regional level by weighting each subregion by its share of total harvested cotton acreage within the region.

Cultural Factors

The most important cultural practice affecting yields has undoubtedly been the planting of cotton in "skip-row" patterns. Alternating rows of cotton with strips of idle land increases yields by allowing more sunshine to reach the plants and by giving them additional room in which to grow and mature. Yields are computed on a cotton acre rather than a land acre basis.

Equations

The reported equations represent the "best" of the several specifications estimated per region.

Delta

The estimated yield equation is (*t*-values in parentheses):

$$
\begin{aligned}
Y = \underset{(2.9)}{428} - \underset{(2.3)}{34HA}\ \underset{(2.8)}{39.1TI} + \underset{(1.2)}{11.1T2}& \\
+ \underset{(1.9)}{0.155SKIP} - \underset{(1.7)}{23RAINOND}& \\
- \underset{(2.7)}{238D74}& \qquad (5)
\end{aligned}
$$

where:

Y	=	yield of cotton lint, pounds per harvested acre
HA	=	harvested acres, millions
TI	=	1, 2, ---, 15, representing trend in Delta yield from 1951-65; 0 elsewhere

[6] Preplanting, January-March; planting, April-May; growing, June-July; maturing, August-September; and harvesting, October-December.

T2	=	1, 2, ···, 9, representing trend in Delta yield from 1966-74; 0 elsewhere
SKIP	=	acres of cotton planted in skip-row planting (two or fewer rows skipped), thousands of acres
RAINOND	=	departure from normal of Delta rainfall during harvest season, in acre-inches
D74	=	0, 1 variable to account for subnormal temperature in the fall of 1974.

The equation explained 79 percent of the variability in Delta yields over the historical period, with a standard error of 49 pounds. The coefficients are easily interpreted. For example, a 1-million acre increase in harvested acreage will cause per acre yield to decline 34 pounds; 100,000 acres planted in skip-row patterns (2 or less rows skipped) will lead to a 15.5-pound per acre increase. Rainfall averaging 1 acre-inch above normal in the fall will cause average yields to decline 23 pounds per acre.

Southeast

The estimated yield equation is:

$$\underset{(1.6)}{Y = 179} + \underset{(1.7)}{6.2PCT/INC} - \underset{(2.3)}{26HA} + \underset{(3.7)}{8.0T1} + \underset{(2.0)}{10.0T2} + \underset{(1.4)}{12.4SUMRAIN} \qquad (6)$$

where previously undefined variables are:

PCT	=	cotton farm price, January-April, cents per pound
INC	=	index of production costs in the region, 1967 = 1.0
SUMRAIN	=	departure of rainfall in the region from normal during growing season, acre-inches.

The equation explained 72 percent of the variation in Southeastern cotton yields during 1951-74, with a standard error of 27 pounds. Southeastern yields are responsive to changes in the deflated price of cotton. At approximately current price and cost levels, an increase of 5 cents per pound in cotton price would lead to an estimated yield increase of 3-1/2 pounds per acre.

Southwest

The estimated yield equation is:

$$Y = \underset{(28.9)}{457} - \underset{(11.4)}{22HA} + \underset{(5.3)}{0.035SKIP} + \underset{(3.3)}{24RAINJFM} + \underset{(2.7)}{11RAINJJ} - \underset{(8.2)}{99SWFREZ} \qquad (7)$$

where previously undefined variables are:

RAINJFM	=	departure from normal of Southwestern rainfall during January-March, acre-inches
RAINJJ	=	departure from normal of Southwestern rainfall during June and July, acre-inches
SWFREZ	=	0, 1 variable to account for subnormal temperatures in the region in 1969-71 and 1974.

The equation explained 95 percent of the variation in Southwestern c tton yields during 1951-74, with a standard error of 18 pounds. The importance of preplanting period moisture (RAINJFM) is emphasized—yield changes by 24 pounds per each acre-inch above or below normal. A 1-million increase in harvested acreage is estimated to drop yield 22 pounds.

West

The yield equation is:

$$Y = \underset{(0.3)}{56} + \underset{(2.3)}{8.4PCT/INC} + \underset{(6.8)}{93TW} + \underset{(2.8)}{0.255SKIP} - \underset{(2.6)}{126WEFREZ} \qquad (8)$$

where the previously undefined variables are:

TW	=	1, 2, ···, 6, trend in Western yields 1951-55; held constant, thereafter
WEFREZ	=	0, 1, variable to account for subnormal temperatures in 1969-71

This equation explained 83 percent of the variation in Western cotton yields, with a standard error of 60 pounds. Unlike behavior in the other regions, harvested acreage had no influence on yields, probably because acreage is virtually all irrigated.

IMPLICATIONS

Cotton production response to price has been shown to depend upon the relative responses of acreage to price, yield to acreage, and yield to price; see expression (11). Desired increases or decreases in output of cotton (or other crops) may be stimulated by Government policy. Acreage levels can be changed through increases or decreases in the support price (if production decisions are based on these, rather than market prices), or through policies to take land out of production such as the set-aside programs.

Knowledge of the responses embodied in expression (11) and of their regional differences will help policymakers decide on changes in support prices or, for example, the levels of cropland setaside percentages necessary to achieve production goals. Moreover, knowledge of these relationships should help economic analysts in forecasting and analyzing cotton production response to economic and policy variables.

Estimated Relationships

In table 2, values of $E_{Q/P}$, $E_{HA/P}$, and $E_{Y/HA}$ are presented. These elasticities apply to average cotton price, yield, harvested acreage, and production for the 1973-77 crop years.

To achieve a 10-percent decrease in regional production, required acreage cuts ($10 \div E_{Q/HA}$) would range from 10 percent in the West to 15 percent in the Southwest. A flat 10-percent cut in acreage across regions would lower total production only 8.1 percent, based on regional shares of production during the past 5 years. To reduce output 10 percent, cuts in acreage of about 13 percent would be required.

If economic conditions were such that cotton producers were basing their production decisions on support prices, what percentage increase in cotton's support price would be required to induce a 10-percent increase in production? The values of $E_{Q/P}$ indicate that a 10-percent increase in the support price would lead to production increases from just 2.2 percent in the Southwest to 19.5 percent in the Southeast. However, over the past 5 years, the Southwest has produced about 34 percent of the U.S. total, while the Southeast has produced just 8 percent (Delta, 28 percent; West, 26 percent). Based on regional shares of production, the U.S. value of $E_{Q/P}$ is estimated to be 0.84.

To achieve a 10-percent increase in production, a price increase of 12 percent is thus required. Traditionally, this type of question has been answered by estimating the price increase required to raise acreage 10 percent because of the assumed equivalency of percentage changes in acreage and production. However, a 13.2-percent increase in support price would be needed to increase acreage 10 percent since the value of $E_{HA/P}$ for the United States is 0.76. Such a price increase would expand production an estimated 11.1 percent (0.84 times 13.2), slightly above the target value of 10 percent.

Table 2—Relationships between cotton production acreage, yield, and price, by region[1]

Region	$E_{Q/P}$	$E_{Y/P}$	$E_{HA/P}$	$E_{Y/Ha}$	$E_{Q/HA}$[2]
Delta	0.87	[3]0	1.16	−0.25	0.75
Southeast	1.95	0.67	1.36	−0.06	0.94
Southwest	0.22	[3]0	0.33	−0.34	0.66
West	1.22	0.33	0.89	[3]0	1.00

[1] 1973-77 base; relationships defined in text. [2] $E_{Q/HA} = 1 + E_{Y/Ha}$. [3] Variable was insignificant in the yield equation.

In Earlier Issues

Soil scientists have found that on many soils the expected yields are closely related to the depth or thickness of the topsoil that is present. Further reductions in the depth of topsoil in such instances will have a predictable effect on the yields. The value of topsoil in terms of crop yields will vary, depending on the type of subsoil and the parent material. Then there are some soils, especially in the Southeastern States, in which the subsoil has a better capacity for holding moisture and fertilizer than has the present topsoil; in such cases the loss of topsoil may even increase productivity. But these cases are the exception. Most of the results of experimental studies in the Northern States indicate that crop yields decrease as topsoil is lost and that the decrease in yields per inch of topsoil loss usually increases as additional inches of topsoil are eroded away.

George H. Walter
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