TECHNICAL CHANGE AND THE DERIVED DEMAND FOR COTTON IN THE U.S. TEXTILE INDUSTRY

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Domestic mill use of cotton is the most important component of total demand for U.S. cotton, accounting for more than half the latter for most of the period 1950-1987. Domestic mill demand for cotton has experienced a long-term declining trend. The average annual mill use of cotton fell from 9.21 million bales in 1950-1954 to 5.67 million bales during 1981-1985. Concurrently, manmade fibers have been substituting for cotton at a rapid rate. Representing only about 20 percent of the domestic fiber market in 1950, manmade fibers now comprise nearly 75 percent of today's market. In contrast, cotton, which made up 69 percent of U.S. mill fiber use in the early 1950's, has fallen to about 25 percent in recent years.

Over the past forty years, much research has modeled and investigated the demand for cotton and substitution among fibers [Lowenstein (1952), Ward and King (1973), Lewis (1972), Wohlgenant (1986), and Jones-Russell (1987)]. Most of that research has not considered technical change as a possible cause of the observed trends in fiber use and has attributed changes in fiber demand to changes in relative fiber prices and income and to increases in textile imports. Casual evidence suggests that these factors may not account for all the decline in mill use of cotton. Figures 1.a and 1.b show the trend in mill demand for cotton and manmade fibers and the movement of their relative prices for the period 1950-1987. It shows that the mill use of manmade fibers began to supplant cotton in the mid 1960's and has continued a strong increasing trend since then, while cotton use decreased despite co-movement of the two fiber prices after 1970. The figures suggest that some other important factors may play a part in explaining the change in mill demand for fibers. Ward and King (1973) have noted that technical innovation in the textile industry has had an important impact on interfiber competition, especially when aggregate data is examined.

In recent decades, the textile industry has experienced considerable technical innovations: from the 1950s with introduction of the shuttleless loom, which revolutionized the weaving process to today's automation of textile production; computer design of fabrics, use of "nonwoven" fabrics assembled without weaving, and new fiber-blending technologies. These innovations have come about with a considerable increase in capital intensity of the U.S. industry, often referred to as "capital deepening" [Cable (1987)]. This capital deepening process in U.S. textile production has created greater possibilities for manmade fibers to substitute for cotton and other natural fibers independent of relative fiber-prices changes.

The objective of this paper is to assess the impact on fiber use of technical advances in the U.S. textile mill industry. Using a dual approach, the paper estimates a linear logit model of the fiber cost shares of the U.S. textile mill production with time-series data for the period 1950-1987. Hence, the estimated system of fiber demands is based on production theory and abstracts from final consumption considerations. This approach is convenient because it is consistent with the data aggregation (standard industry classification 22) and with cost-minimizing behavior in production. We decompose fiber use into three categories: cotton fiber, manmade fiber and wool. Technical change is approximated by an index of capital intensity that is described further later in the paper.

Many studies report that flexible functional forms such as the translog cost function exhibit the proper curvature characteristics for only a limited range of the data set [Barnett and Lee (1985), Considine (1989), Diewert and Wales 91987), and Chang, Beghin and Sumner (1987)]. The logit model of cost shares used in this study presents decisive advantages [Considine and Mount

(1984)]. Since the price elasticities of demand are linear in shares, they are less sensitive to extreme share values, and if concavity conditions hold at the mean, then negativity holds for the entire range of the data [Considine (1989)]. Furthermore, a dynamic adjustment process easily can be introduced by including a partial adjustment process in input levels.

Our results suggest that technical change has adversely affected the demand for natural fibers (cotton and wool) in favor of manmade fibers. Our definition of textile output includes textile mill products and excludes end-uses such as apparel. Since mill demand for fibers represents the bulk of the derived demand, it is reasonable not to involve end-use industries such as apparel in this study.

Textile mill manufacturing involves several intermediate production stages such as spinning, weaving, knitting and dyeing. Substitution possibilities among fibers and technical innovation may differ in the different production stages. Unfortunately, data on these different mill manufacturing steps are difficult to obtain. This limitation precludes modeling every stage of the production. Therefore, our model aggregates the different mill production stages into a single process and the corresponding aggregate data are used. All firms in the industry face the same price vector, behave competitively, minimize cost of production, and each firm's production function exhibits constant returns to scale; these usual assumptions are necessary to obtain the industry's cost function by aggregation over firms.

The aggregate cost function can be described as

$$(1) \quad C(P, y, T) = \min \{Px: y \epsilon V(x,T)\}$$

where P is the vector of input prices, y is the output, x is the vector of inputs (capital, labor, energy and fibers), T represents the technology change and V is the input requirement set.

Weak separability in cost minimization implies a two-stage optimal procedures in the producer's decision-making. Homotheticity is a necessary and sufficient condition for this two-stage decision [Fuss (1977)]. The empirical evidence for homothetic production is mixed. Considine's empirical work supports the separability assumption. Monke and Taylor (1985) find that there is an invariant relationship between total fiber use and textile output thereby providing support for the independence of the optimum fiber mix from other nonfiber input prices. Hence, we assume that the cost-minimizing choice of fibers is independent of the optimal decision about other inputs even though the level of total fiber use is not. Therefore, the subset cost function of fibers is

$$(2) \quad C_F = C_F(P_C, P_M, P_W, y, T) \quad ,$$

where C_F is the subset cost function for all fibers, and P_C, P_M, and P_W are the prices of cotton, manmade fibers and wool respectively. If the total cost function is well-behaved, the subset function C_F must be linear homogeneity in prices, symmetric and concave in fiber prices. By Shephard's Lemma, the derived demands for fiber inputs are the partial derivatives of C_F with respect to the three fiber prices, i.e.,

$$(3) \quad x_i = \partial C_F/\partial P_i = x_i(P_C, P_M, P_W, y, T) \quad ,$$

where x_i is the quantity demanded for the ith fiber (i - C, M, W). Assuming constant return to scale, the fiber demand function can be redefined as $x_i = yx_i^*(P_C, P_M, P_W, T)$, where x_i^* is the fiber demand per unit of output.

Traditionally, a "time" counter is used to represent technical change [Chambers (1988)], but this approach yields estimates without clear economic meaning and does not account for time-uneven technical changes. Since technical progress in the U.S. textile industry usually has been associated with an increase of the capital intensity (adoption of new machines and equipment), the capital stock index is used to capture this capital-deepening phenomenon.

The adjustment of fiber demand to prices and technical changes is constrained by purchase and installation of new machines and equipment. Adjustment costs characterize the gradual response of firms to shift in demand for fibers; we incorporate a Nerlovian partial adjustment process in fiber quantities to describe this gradual response.

The linear logit cost function

Violations of concavity and negativity are recurrent problems in estimating cost functions [Diewert and Wales (1987)]. Lau (1978) and Gallant and Goulb (1984) proposed methods for imposing the appropriate curvature conditions locally, and Diewert and Wales (1987) have suggested the biquadratic function form to impose the correct curvature conditions in a global manner without destroying the flexibility of the functional form. Other authors suggest using Bayesian techniques to impose concavity restrictions [Geweke (1986), Chalfant and White (1987), Chang, Beghin, and
V Sumner (198~~7~~8)].

We use a simpler alternative proposed by Considine and Mount (1984), which is the linear logit model of cost shares. The linear logit model of input demand is derived from the cost share equations. By Shepard's Lemma we have

$$(4) \quad S_i = (P_i(\partial C/\partial P_i)/(\Sigma_J P_j(\partial C/\partial P_j) \quad , \quad \text{for } i,\ j = C,\ M,\ W.$$

Logistics functions are used to define the share equations directly:

$$(5)\quad S_i = (e^{f_i})/\sum_j e^{f_j} \qquad \text{with} \qquad f_i = \eta_i + \sum_{j=1}^{n}\rho_{ij}\ln P_j + \tau_i T,$$

where T is the index of technical change and η, ρ, and τ are unknown parameters. The logarithm of the logistic share equation is

$$(6)\quad \ln(S_i) = f_i - \ln(\sum_j e^{f_j}).$$

The input shares are logit functions satisfying adding-up and non-negativity conditions implied by neoclassical demand theory. Next we differentiate the cost shares with respect to prices; this step gives

$$(7)\quad H_{iK} = \partial\ln S_i/\partial\ln P_K = \rho_{iK} - \Sigma s_j\rho_{jK}.$$

Then the cross- and own-price elasticities are

$$(8)\quad E_{iK} = H_{iK} + S_K \qquad \text{and} \qquad E_{ii} = H_{ii} + S_i - 1.$$

Allen-Uzawa elasticities of substitution are given by

$$(9)\quad \sigma_{iK} = E_{iK}/S_K.$$

The effect on fiber use of technical change is given by

$$(10)\quad \partial\ln S_i/\partial T = \theta_i.$$

If $\theta_i = \theta_K$ for all i and k, technical change is share neutral, which implies that it does not cause a shift in demand for inputs. Technical change is said to be share i-using if $\theta_i > 0$ and share i-saving if the opposite inequality holds [Chambers (1988)].

One drawback of the logit model is that symmetry can be imposed only locally. The mean of the data set is a natural choice although not unique. Under the assumptions of non-neutral technical change, dynamic adjustment, zero-degree homogeneity in fiber prices and symmetry at the mean, the cost share is specified as follows:

$$\begin{aligned}(11.1)\ln(S_{Ct}/S_{Wt}) = {} & (\alpha_C - \alpha_W) - [S_M^*\beta_{CM} + (S_C^* + S_W^*)\beta_{CW}]\ln(P_{Ct}/P_{Wt}) + \\ & (\beta_{CM} - \beta_{MW})S_M^*\ln(P_{Mt}/P_{Wt}) + (1 - \delta)\ln(C_{t-1}/W_{t-1}) + (\theta_1 - \theta_3)T_t \\ & + (\epsilon_{Ct} - \epsilon_{Wt}),\end{aligned}$$

$$
\begin{aligned}
(11.2)\ln(S_{Mt}/S_{Wt}) &= (\alpha_M - \alpha_W) - [S_C^*\beta_{CM} + (S_M^* + S_W^*)\beta_{MW}]\ln(P_{Mt}/P_{Wt}) \\
&\quad + (\beta_{CM} - \beta_{CW})S_C^*\ln(P_{Ct}/P_{Wt}) + (1 - \delta)\ln(M_{t-1}/W_{t-1}) + (\theta_2 - \theta^3)T_t \\
&\quad + (\epsilon^{Mt} - \epsilon_{Wt}),
\end{aligned}
$$

where subscripts C, M and W refer to cotton, manmade fibers and wool; S_i^* are the mean cost shares, P_i refers to mill-delivered fiber prices, and $(\epsilon_{it} - \epsilon_{Mt})$ are assumed to be normally distributed random disturbances. The estimation uses time-series data for the period 1950-1987. All data except the technical change index are compiled from various issues of "The Cotton and Wool Situation and Outlook" (USDA), "Business Statistics," "The Statistical Abstract of the United States" and "Annual Survey of Manufacturers" (USDC). Manmade fibers quantities and prices are computed by aggregating polyester and rayon into a single fiber type. No capital data is readily available but the capital stock can be estimated from data on investment, depreciation, and an existing incomplete capital stock series. Data about capital expenditures and depreciation in the U.S. textile industry are available from USDC, which also published capital stock data for 1979 to 1983. The capital price index comes from USDC and is used to deflate expenditure and depreciation nominal data. The real capital stock is computed by aggregation of net investment and is adjusted for consistency with the capital stock series. Then the real capital data are indexed to construct our technical change index with base year of 1981.

The model is estimated using seemingly unrelated regression. The hypothesis of share-neutral technical change is tested and rejected at the 5% significance level. The estimating results are reported in Table 1.a. All technical change coefficients are significantly different from zero at the 10% significance level. Both technical change coefficients for cotton and wool

Table 1.a: Estimates of Cost Share Equations for 1950-87

$(\gamma_C - \gamma_W)$	1.2473	(5.549)	β_{MW}	0.9597	(3.594)
$(\gamma_M - \gamma_W)$	0.6899	(4.724)	β_{WW}	-0.6809	(-3.186)
β_{CC}	1.0636	(5.421)	θ_1	-0.1098	(-1.672)
B_{CM}	0.5443	(1.406)	θ_2	0.3455	(2.708)
B_{CW}	0.3285	(1.165)	θ_3	-0.2356	(-5.610)
B_{MM}	-0.2464	(-2.540)	$(1 - \delta)$	0.5185	(6.298)

System weighted R-squared: 0.9748

(Numbers in parentheses are t-statistics.)

Table 1.b: Fiber Price and Substitution Elasticities

PRICE ELASTICITIES

Short-Run

	Cotton	Manmade Fiber	Wool
Cotton	-0.499	0.837	0.030
Manmade Fiber	0.540	-0.789	0.058
Wool	0.257	0.765	-1.026

Long-Run

Cotton	-0.964	1.615	0.058
Manmade Fibers	1.042	-1.521	0.112
Wool	0.495	1.476	-1.979

ALLEN- UZAWA PARTIAL ELASTICITY OF SUBSTITUTION

Short-Run

	Cotton	Manmade Fiber	Wool
Cotton	-1.333	1.441	0.687
Manmade Fibers		-1.357	1.317
Wool			-2.327

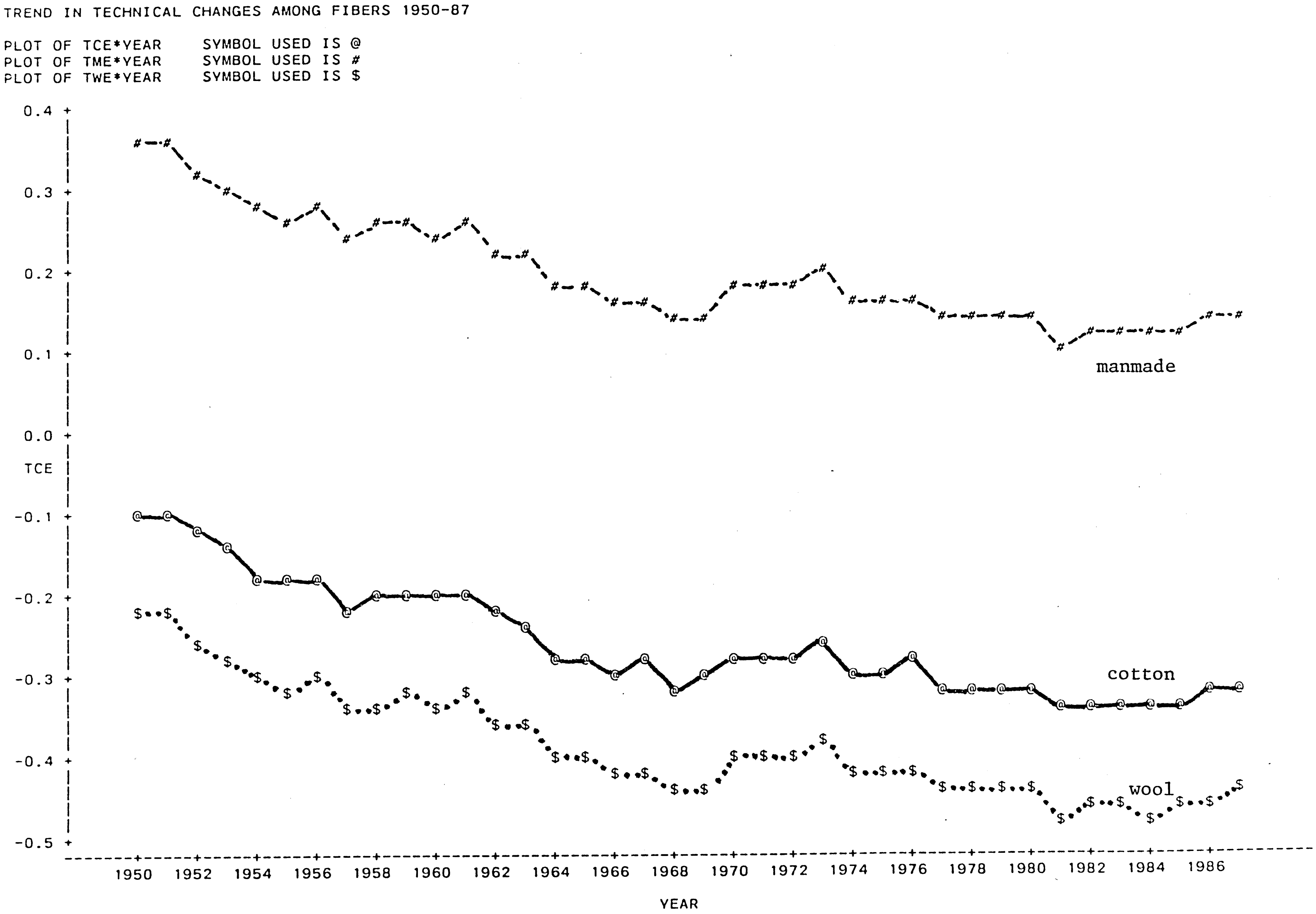
Long-Run

Cotton	-2.571	2.779	1.325
Manmade Fibers		-2.618	2.541
Wool			-4.488

are negative but that for manmade fibers is positive. This suggests that as technological progress is made in the textile industry, the industry demands more manmade fibers but less cotton and wool. Such biased technical progress changes relative fiber use in favor of manmade fibers. Figure 2 presents this interesting movement of share elasticities with respect to the technical change index from 1950 to 1987. Both cotton and wool have negative share elasticities, which suggests that the U.S. textile industry uses less and less of these fibers as the new technology is adopted. The positive elasticity for manmade fibers suggests that technical change has been playing an important role in promoting the use of this type of fiber. Finally, all these share elasticities fluctuate over time, which suggests that technical changes in the textile mill industry are not even. Relative price changes also play an important role in changing the fiber demand structure. Table 1.b presents price and Allen partial substitution elasticities estimated at the mean cost shares. The short-run own price elasticity of cotton is fairly inelastic but relatively larger than many previous estimates, such as -0.1 in Ward and King (1973), -0.17 in Lewis (1972), and -0.297 in Wohlgenant (1986). The elasticity evaluated at the mean cost share during 1978-1987 is -0.639, which is almost twice as large as the estimate for 1950-1959 (-0.332). During the same period, the elasticity of substitution of manmade fibers for cotton has increased significantly, from 1.26 to 1.57.

Finally, the long-run cross price elasticities of manmade fibers with respect to cotton and wool prices are elastic, and reflect the high substitution possibilities among the fiber types.

Figure 2 Share Elasticities with respect to Technical Change



Conclusions

In the past forty years, the textile mill industry has experienced profound technical changes characterized by a long phase of "capital deepening." Such changes have had important biased effects on mill fiber consumption and caused intensification of the use of manmade fibers and a decline in the consumption of natural fibers. Accounting for the impact of technical change, our results yield larger estimates of price and substitution elasticities than most previous estimates.

Our results obviously are tentative. Homotheticity was a maintained hypothesis in the estimation, but it could be tested. A finer disaggregation of manmade fiber could also reveal effects lost in the current aggregation. Textile mill output also has experienced changes in attributes, reflecting consumer need for more convenient textile products. Future work could incorporate in the estimation variables summarizing the change in attributes (e.g., an index of fiber blend content) of textile output and could attempt to identify the impact of these changes on fiber use, in addition to changes in relative prices and technology.

The capital intensification of the U.S. textile industry is likely to go on given the competitive pressure of foreign producers which rely on advantageous labor cost. Our model and results could contribute to predict the likely impact of this continuing capital deepening on the future fiber use of the U.S. textile industry.

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