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Technical Change And Growth In The Textile Industry: The Nonwoven Sector

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ABSTRACT

We examine the performance of a growing sector of the textile industry: nonwoven fabric mills. This sector is emerging from what was once a marginal manufacturing sector to become increasingly a focus for the future of textiles in the US. From disposable diapers to bleach wipes, medical apparel to house wrapping, new products are entering the market; these products are made possible by technological advancements in adhesion techniques, fiber modifications and delivery advancements. In order to better understand these significant industry dynamics, we estimate a translog cost function to calculate the elasticity of substitution between capital, labor, energy and materials and to see how these change over time. Additionally, we track trends in the elasticity of scale and the impact of technological change. Textile manufacturing in the United States is shifting away from commodity products and the innovative nonwovens sector provides a much needed exemplar for future textile manufacturing.

INTRODUCTION

Dire news regarding the U.S. textile industry is manifest. At the aggregate industry level, many of these claims are correct. However, a very different picture emerges from data from the individual sectors of the textile industry where there is tremendous creative energy. Levinsohn and Petropolous (2001) present the industry as an example of “creative destruction", a term made famous by Joseph Schumpeter. His idea is that the *creation* of new products and production methods lead to the *destruction* of market share for firms committed to existing paradigms. The evolution of the nonwoven sector in the last thirty years has certainly been creative and is changing textile manufacturing in the United States.

THE NONWOVEN MANUFACTURING SECTOR

The Importance Of The Nonwovens Sector

The textile industry is an important manufacturing sector; it contributed close to $69 billion to GDP in 2005 (BEA, 2007); in certain regions of the United States, it is the predominant employer although those numbers are declining. Within the textile industry, the nonwovens sector is distinguished for its *growth;* this is in contrast to many other textile sectors. In 2002, the sector employed more than 21,000 employees (Census, 2007)[1] at average wage rates above the typical textile worker. The following graph, Figure 1, tracks the changes in employment from 1958 through 1996.

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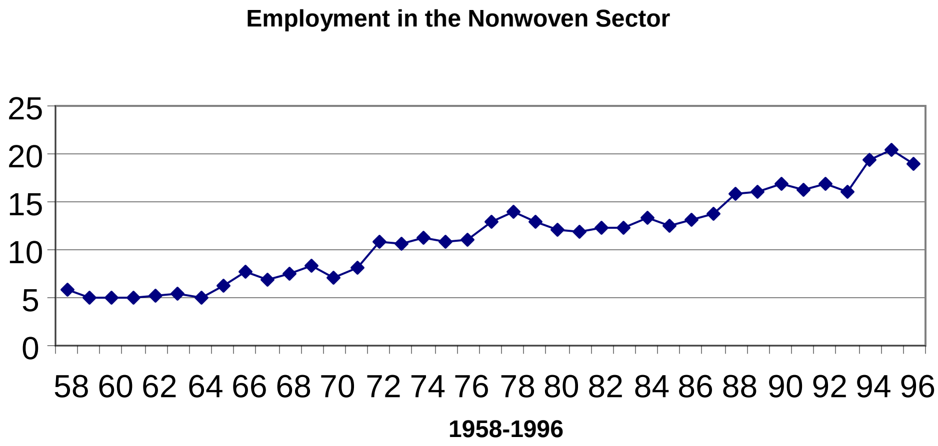
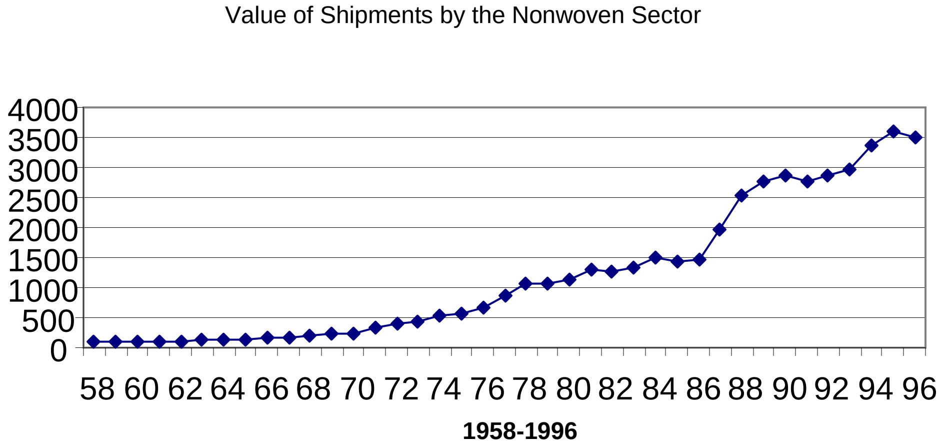
[1] The US Census Bureau conducts surveys every 5 years, the next survey will be distributed Dec. 2007, making data from 2002 the most current. The graphs show data until 1996 as the Standard Industrial Code (SIC) was replaced at that time by the North American Industrial Classification System (NAICS) which does not yet contain enough years to perform significant statistics. SIC 2297is not equivalent to NAICS 313230 as the later also contains data for miscellaneous textiles, SIC 2299.

Figure 1: Employment Trends (thousands)



The number of firms entering the industry continues to grow as does sales volume, measured by value of shipments in Figure 2, as new uses of nonwovens continue to be developed.

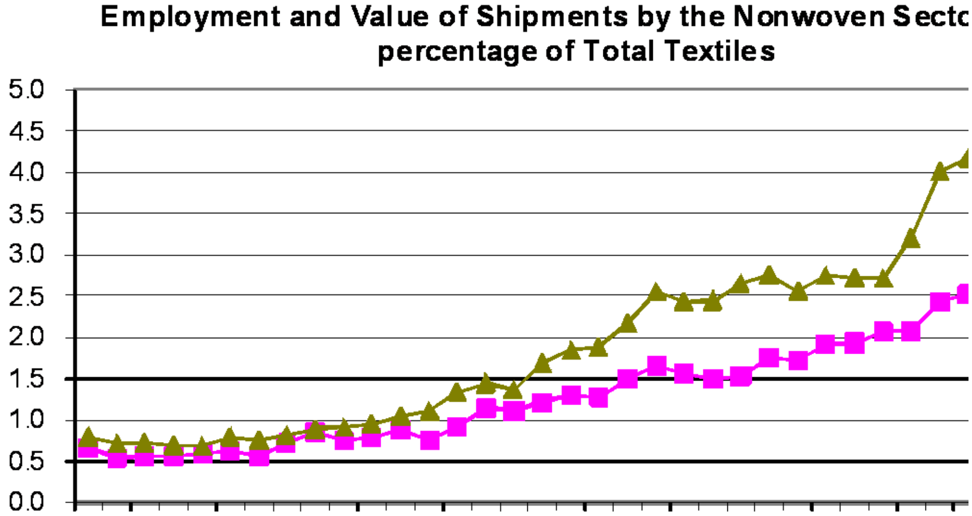
Figure 2: Output of Nonwoven Sector (millions)



Source: NBER Manufacturing Productivity Database

The following table shows these trends relative to the textile industry as a whole.

Figure 3: Growth of the Nonwovens Sector



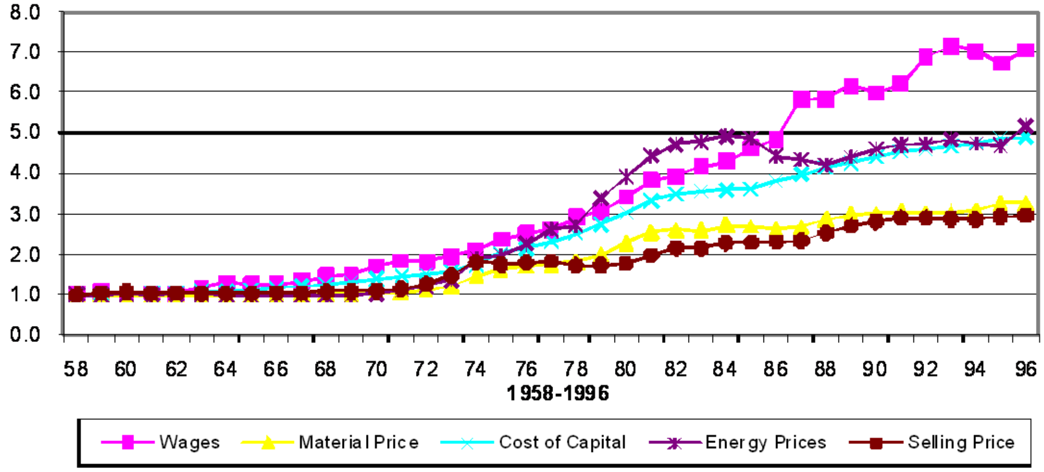
Source: NBER Manufacturing Productivity Database

Evolution Of Nonwoven Products And Production Costs

In the 1950’s, the Kendall Co. produced a nonwoven cotton cloth to clean photographic plates that was superior to the rolled cotton used previously. In the early 1970’s, growth accelerated due to process innovations that lead to the introduction of disposable diapers. (source?). Later, the nonwovens sector included molded car interiors, house wrap, industrial and medical apparel. Products evolve as the cost, performance and product characteristics benefit from technological advances in formation processes.

At the same time that production processes and products were swiftly evolving, energy and labor prices were also increasing, outpacing increases in the final prices for output. The chart below highlights these price pressures.

Figure 3: Price Indices for Nonwovens



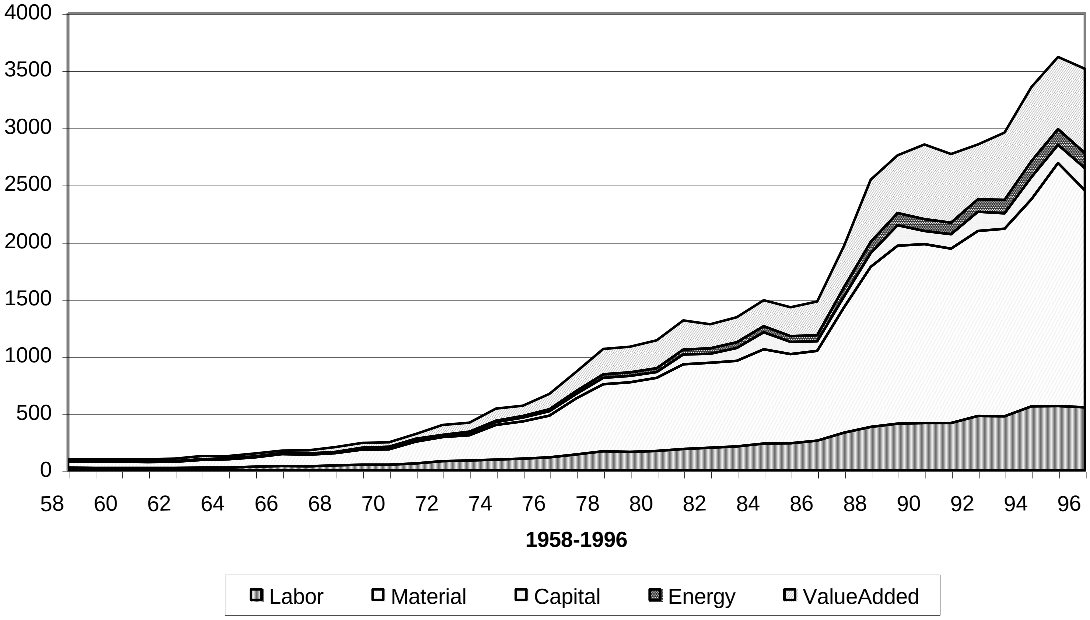
Source: Bureau of Labor Statistics, http://bls.gov

The price index for labor shows the greatest increase over the period. The second greatest increase is in the price of energy, which is also the most variable, however not a significant share of the overall cost structure facing the firm, as illustrated in the following chart. Similarly, the increase in the price of investment in capital is large but again not a large expenditure relative to total costs. The most modest price increase is for the final product; good news for the consumer but not the manufacturer. Nonwoven prices for the final goods increased by 196% while overall, the cost of commodities increased 305.8% between 1965 and 2002 (Carpet & Rug Institute, 2003).

While these profiles are not uncommon within the textile industry, there are two substantial differences in the nonwovens sector. First, the cost of material very closely tracks the price index for shipments (the price of the final product). The general pattern in textiles is for material costs to increase by much more than output prices. Secondly, the capital intensive manufacturing protects the nonwovens sector from much of the competition from abroad. Governments of developing countries tend to avoid subsidizing industries requiring large capital investments and small workforces; they generally have the objective of increasing employment opportunities for their labor force.

The following chart shows the importance of materials in the cost structure.

Figure 4: Sum of Costs and Value Added



Source: NBER Manufacturing Productivity Database

Material costs went from 65 to 70 percent of the costs of production, while labor shifted from 30 to 20 percent of the costs, and the rest is accounted for by energy and capital, which together went from 5% to 10 % of the total cost of production.

Thus we observe a) large changes in the relative prices of inputs and b) the importance of materials in the cost structure of the firm. Rising labor costs favor the labor-saving technology of the nonwovens processes. Technological innovations in the production process continue to encourage growth in the industry with new product development and product quality improvements. We apply econometric techniques to analyze this sector's success, particularly with regard to changing patterns of input use, that is, the degree of substitutability between inputs as costs change, as well as determine the economies of scale.

Next, we first present the theoretical model and the description of the dataset. Then the econometric estimation and analysis of the nonwoven sector provides insight for textile manufacturing in the future.

ECONOMETRIC ANALYSIS

Theoretical Model

We employ the transcendental logarithmic (translog) cost function to study the production structure of the nonwoven sector. The translog cost function developed by Christensen, Jorgensen and Lau [1971, 1973] handles multiple inputs and allows for variable elasticities of substitution between these inputs. This is preferable to the Cobb-Douglas and constant elasticity of substitution (CES) production functions that only allow us to analyze two inputs, usually capital and labor, and restrict the elasticity parameters to sum to unity (Cobb-Douglas) or be constant (CES).[2]

Assuming firms minimize total costs of production, the general form of the aggregate cost function can be represented as

$$\min C = G(P_K, P_L, P_E, P_M, Q, T) \tag{1}$$

where production cost (C), is expressed as a function of the prices of inputs (capital, labor, energy, materials), the level of output (Q) and technical change (T). The general form of the cost function is expressed in its translog form [Christensen et al. (1973)] as

$$\begin{aligned} \ln C = {} & \alpha_0 + \alpha_q \ln Q + + \Sigma_i \alpha_i \ln P_i + \tfrac{1}{2} \gamma_{qq} (\ln Q)^2 \\ & + \tfrac{1}{2} \Sigma_i \Sigma_j \gamma_{ij} \ln P_i \ln P_j + \Sigma_i \gamma_{iq} \ln P_i \ln Q \\ & + \Sigma \theta_{it} \ln P_i T + \theta_{qt} \ln QT + \beta_t T + \tfrac{1}{2} \beta_{tt} T^2 \end{aligned} \tag{2}$$

where $i,j = K,L,E,M$, and α, β, γ, Θ are the parameters to be estimated. To streamline the exposition, econometric specifics are articulated separately in the following sections of the econometric results, and in full in the appendix.

The model is estimated using the iterative Zellner procedure for seemingly unrelated regressions using the RATS software. The estimated cost function is a multi-input, non-homothetic function, which allows for non-constant returns to scale, non-neutral technical progress and variable elasticity of substitution.

Data Sources

This study is based on data for the period 1953-1996. Data on cost and prices of labor, capital service, energy, non-energy materials and real output for nonwoven textiles (SIC 2297) are taken from the Bureau of Labor Statistics' Multifactor Productivity database. Total cost is computed as the total of labor, capital, energy and material cost. Using this data to estimate the parameters of the cost function allow us to investigate the sources of growth for the nonwovens sector. Specifically, we investigate whether this sector was able to take advantage of economies of scale and how technical change over time has altered the optimal combination and level of inputs.

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[2] For a detailed discussion see Fuss, McFadden and Mundlak (1978), pp. 224-225, and Lau (1986), pp. 1515-1564.

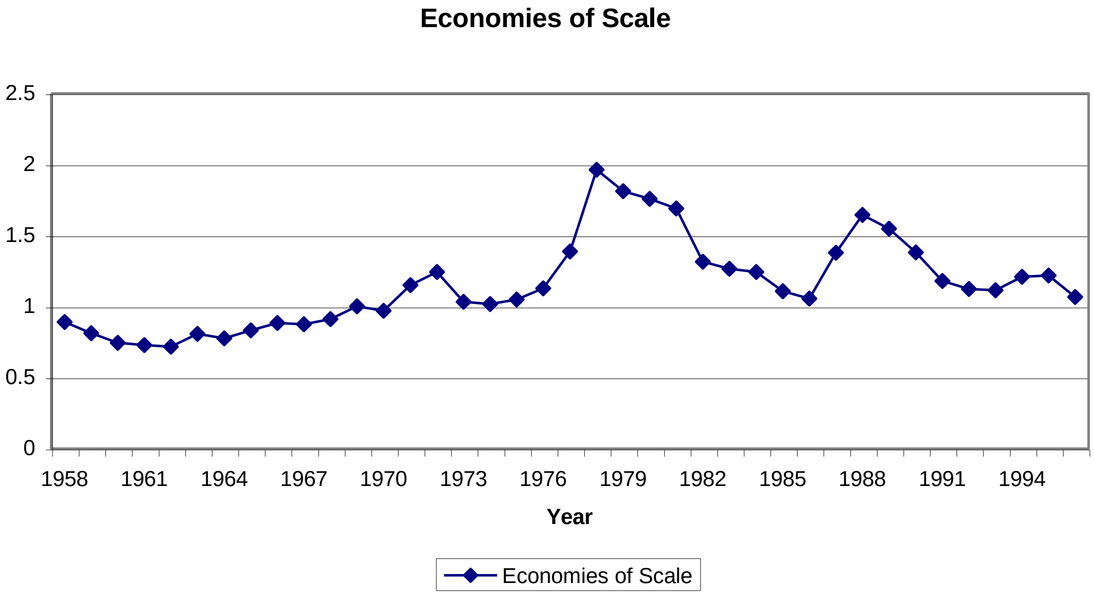
Econometric Estimation And Analysis

Economies of Scale

Scale economies (SE) are measured as the reciprocal of elasticity of cost (ε_{CQ}) or the percentage change in cost with respect to output, holding input prices and technology constant

$$\text{SE} = \left[\frac{\partial \ln C}{\partial \ln Q}\right]^{-1} = \left[\alpha_q + \sum \gamma_{iq} \ln P_i + \gamma_{qq} \ln Q + \theta_i T\right]^{-1} \qquad (3)$$

Constant returns to scale are indicated by SE = 1; costs increase in direct proportion to output. Decreasing returns to scale are indicated by a parameter value SE < 1, that is, costs increase more than proportionate to the increase in output. Our estimates yield the following results.



We observe decreasing returns to scale in the nonwoven sector up until the 1970’s. Before the 1970’s, one would expect firms to be operating at full capacity; expansion causing pressure on the costs. After 1975, however, we see a transformation; SE >1, implying increasing returns to scale. There is sufficient capacity that if the firm expands the scale of operation, they would experience falling per unit costs consistent with a capital intensive industry, requiring large fixed costs. The industry became more efficient between 1978 and 1996, as demand for the nonwoven products grew and mass production allows the firms to take advantage of the scale economies.

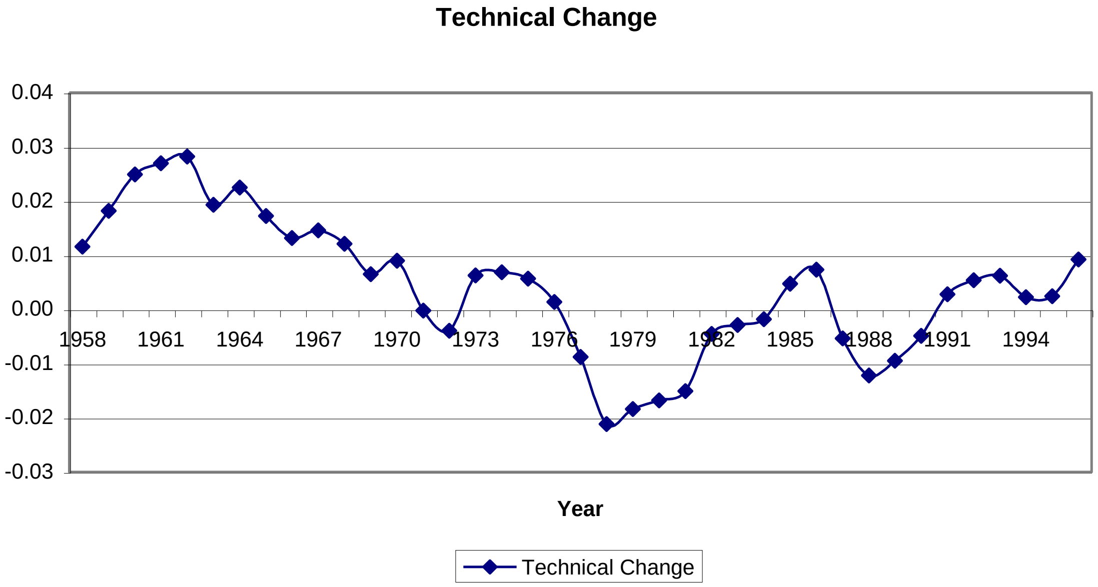
Technical Change

The rate of technical change (TC*)* equals the negative of the rate of growth of total cost with respect to time, holding output and prices of all inputs constant. In terms of the translog cost function, the rate of technical change is measured as,

$$\text{TC} = -\left(\partial \ln C / \partial T\right) = -\left[\beta_t + \sum \theta_{it} \ln P_i + \theta_{qt} \ln Q + \beta_{tt} T\right] \qquad (4)$$

In equation (4) the parameters β_t and β_{tt} measure neutral shifts in the cost function. Thus if β_t <0 and β_{tt} >0, it implies costs decrease over time at an increasing rate, while β_t <0 and β_{tt} <0 implies costs decrease but at the decreasing rate. $\theta's$ measure the biases in technical progress. Technical change is *i*th factor saving if $\theta_{it} < 0$ and factor using if $\theta_{it} > 0$.

Both β_t and β_{tt} are negative and significant in our model estimates (Table 1, appendix), which indicates that production costs are going down over time in the nonwoven sector, but at a decreasing rate. The rate of technical progress for the sample period 1958-1996 averages around 0.4%. This includes periods of negative technical progress (increasing costs) in the late 1970s and mid-1980s, possibly representing periods of energy price shocks and capital investment (see chart below).



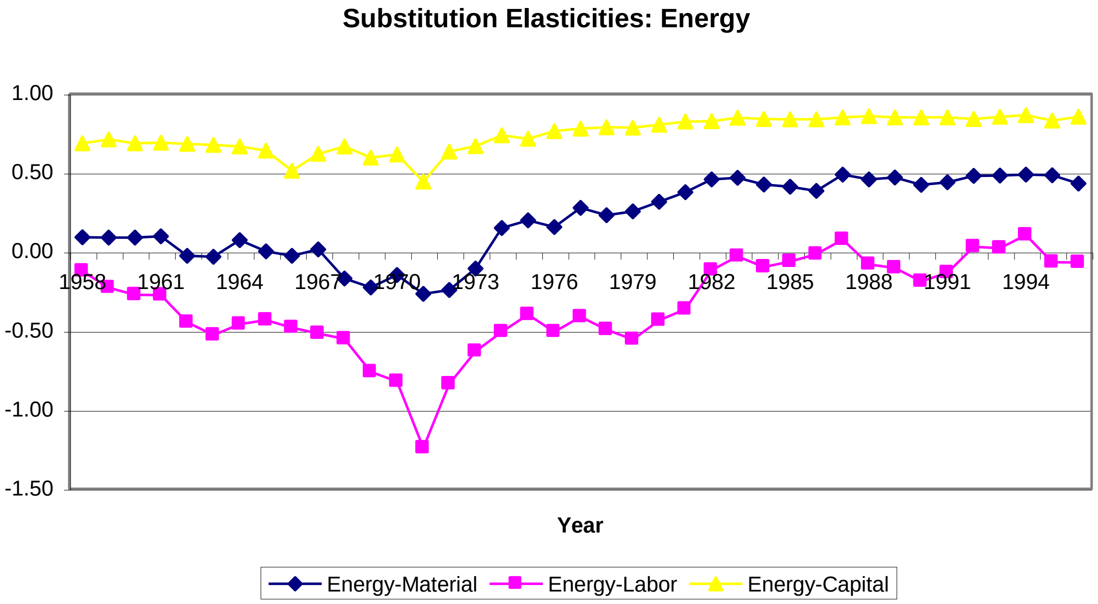
For this sector we find $\theta_{KT} < 0$ and $\theta_{ET} > 0$ which indicate capital-saving and energy using technical progress. An increase in the price of capital encourages the substitution of other inputs which makes the adoption of capital-saving technology more cost effective; this may be attributed to the growing importance of material and labor in the cost structure. Again we see a shift in technology taking place around 1970; the energy using component may be attributed to the increased fuel prices at the time.

Elasticities of Substitution

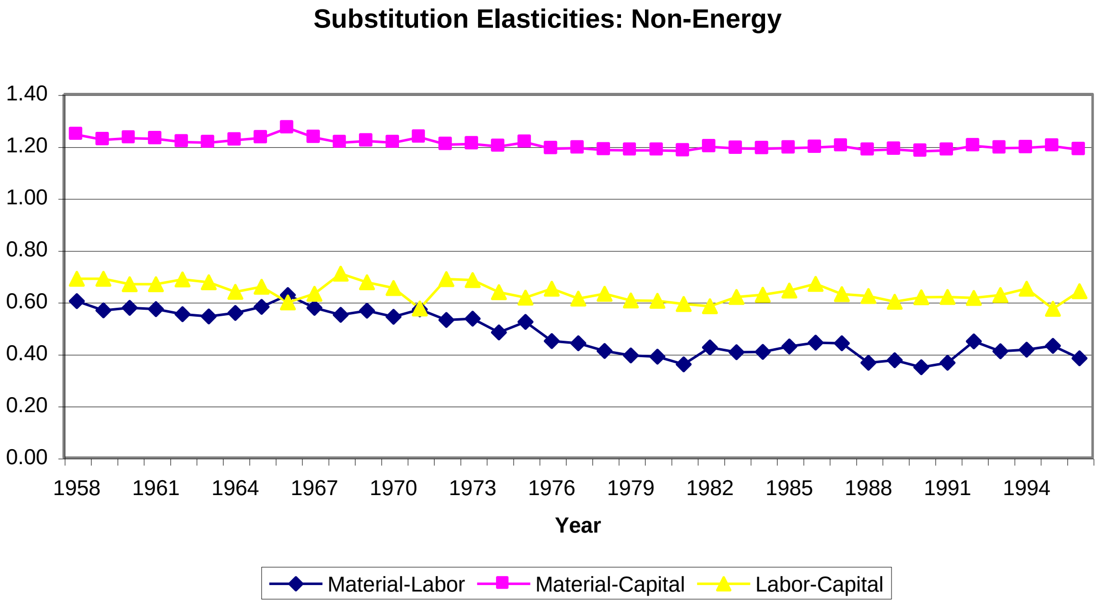
The cost function also yields direct estimates of the various Allen-Uzawa elasticities of substitution. These parameters are the key to describing the pattern and degree of substitutability and complementarity between the factors of production. The Allen-Uzawa partial elasticities of substitution between two factors *i* and *j*, □$_{ij}$, can be computed directly from the translog cost function [Nadiri and Schankerman, 1981].

$$\sigma_{ij} = \frac{\gamma_{ij+}S_i Sj}{S_i S_j}; \qquad \text{for } i \neq j \qquad (5)$$

Having four inputs (labor, materials, capital and energy) creates six pairs for which we estimate elasticities of substitution. To present the results in as clear a manner possible, we segment the elasticities by whether or not energy is in the pair. A positive elasticity indicates that the inputs are substitutes, a negative estimate indicates complements.



Once again a change in technology is in evidence in the early 1970's, energy and materials switch from complements to substitutes. Previous to 1974, if one were to increase production, using more labor or material, one would necessarily use more energy. After 1974, one could substitute more capital or material for energy, perhaps indicating new energy saving capital investment.



While material and capital remain highly substitutable, substitution elasticity between material and labor declines in production. This period covers a technological transition to greater degrees of capital intensity in production. As fewer workers are involved with the production process, they are more critical and less substitutable for other inputs.

The high degree of substitutability between materials and capital might at first blush seem counterintuitive; how can one use more machines and less fiber to achieve a certain level of production? Could one produce the same amount of sweaters, for example, with more looms and less wool? The degree to which capital and material are not complements perhaps reflects the ability of the industry to outsource; that is "to make or buy". If they are making the intermediate inputs, they invest in capital; if the prices shift, an agile manufacturer buys the intermediate inputs (material), thereby substituting material for capital.

CONCLUSIONS

Clearly there has been a fundamental transformation in the nonwovens sector. We attribute this to both product and process innovations. Existing products are being improved (diapers) and new products are continually arising (Clean-up wipes). This is clearly reflected in the data. After 1975, there is a shift to increasing returns to scale in production; there is sufficient capacity that as the scale of operation expands, unit costs fall, consistent with mass production and the large fixed costs of high tech production. Process innovations are evidenced by a shift in technology taking place around 1970 with the growing importance of material and labor in the cost structure. At the same time, energy and materials switch from complements to substitutes. After 1974, one could substitute more capital or material for energy, perhaps indicating new energy saving capital investment.

Material and labor become less substitutable in production; there is a greater degree of capital intensity in production so as fewer workers are involved, they are more critical and less substitutable for other inputs. One would expect capital and material to be used together (complements) but they are substitutes. This reflects the ability of the industry to outsource; that is the "make or buy" decision. Nonwovens, a growing sector of the textile industry, is a paradigm for growth; it exemplifies the value of innovation in an industry often mistakenly dismissed as "old manufacturing".

ACKNOWLEDGEMENTS

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APPENDIX

The cost function is expressed in its translog form, a second-order approximation to an arbitrary twice-differentiable surface [Christensen et al. (1973)]:

$$\begin{aligned}\ln C = {} & \alpha_0 + \alpha_q \ln Q + + \Sigma_i \alpha_i \ln P_i + \tfrac{1}{2}\gamma_{qq} (\ln Q)^2 \\ & + \tfrac{1}{2}\Sigma_i \Sigma_j \gamma_{ij} \ln P_i \ln P_j + \Sigma_i \gamma_{iq} \ln P_i \ln Q \\ & + \Sigma \theta_{it} \ln P_i T + \theta_{qt} \ln QT + \beta_t T + \tfrac{1}{2}\beta_{tt} T^2\end{aligned} \qquad (2)$$

where $i,j = K,L,E,M$, and $\alpha, \beta, \gamma, \Theta$ are the parameters to be estimated.

For a well-behaved cost function, linear homogeneity in input prices and symmetry of the input-price Hessian matrix are imposed.

(i) Linear homogeneity: $\sum \alpha_i = 1$; $\sum \gamma_{ij} = \sum \gamma_{iq} = 0$; $\sum \beta_i = 0$; $\sum \theta_i = 0$ (3)

(ii) Symmetry: $\gamma_{ij} = \gamma_{ji} \quad i \neq j$ (4)

The total cost function is estimated with the cost share equations obtained using Shephard's lemma [Diewert, 1971][3], by differentiating Eq. (2) with respect to the input prices.

$$S_i = \frac{\partial \ln C}{\partial \ln P_i} = \alpha_i + \frac{1}{2}\sum \gamma_{ij} \ln P_j + \gamma_{iq} \ln Q + \theta_i T \qquad i, j = K, L, E, M \tag{5}$$

where $S_i = P_i X_i / C$ is the share of costs accounted for by factor *i*. The cost share equations must satisfy the adding-up criteria i.e. $\sum S_i = 1$.

Scale economies (SC) are measured directly as the reciprocal of elasticity of cost ($>_{CQ}$) with respect to output,

$$\text{SC} = \left[\frac{\partial \ln C}{\partial \ln Q}\right]^{-1} = \left[\alpha_q + \sum \gamma_{iq} \ln P_i + \gamma_{qq} \ln Q + \theta_i T\right]^{-1} \tag{6}$$

which vary with relative factor prices and the levels of output and technology. If SE is greater (less) than unity, cost increases less (more) than proportionally, implying the existence of increasing (decreasing) returns to scale.

The rate of technical change (*TC)* equals the negative of the rate of growth of total cost with respect to time, holding output and prices of all inputs constant.

$$TC = -\frac{\partial \ln C}{\partial T} = -\left[\beta_t + \sum \theta_{it} \ln P_i + \theta_{qt} \ln Q + \beta_{tt} T\right] \tag{7}$$

In equation (7), $\theta' s$ measure the biases in technical progress. Technical change is *i*th factor saving if $\theta_{it} < 0$ and factor using if $\theta_{it} > 0$. The parameters β_t and β_{tt}, measure neutral technical change, characterized by pure shifts in the cost function.

The Allen-Uzawa partial elasticities of substitution between two factors *i* and *j*, □$_{ij}$, and the output-compensated own- and cross-price elasticities of factor demand, □$_{ii}$ and □$_{ij}$, can be computed directly from the translog cost function [Nadiri and Schankerman, 1981]. These parameters describe the degree of substitutability and complementarity between the factors of production.

$$\sigma_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j}; \; \varepsilon_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i} \text{ and } \varepsilon_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i} \qquad \text{for } i \neq j \tag{8}$$

The equality $\sigma_{ij} = \sigma_{ji}$ is ensured by the condition $\gamma_{ij} = \gamma_{ji}$. Also note that $\varepsilon_{ij} = S_j \sigma_{ij}$.

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[3] $\frac{\partial C(q, p)}{\partial P_i} = x_i(q, p)$, where *q* represents output level and *p* is a vector of input prices.

The adding-up condition for the cost shares in (5) renders the disturbance covariance matrix to be singular. Therefore the system of equations is estimated by deleting one of the share equations. The model is estimated using the Iterative Zellner procedure for seemingly unrelated regressions with restrtictions (3) and (4) imposed using the RATS software. Kmenta and Gilbert [1968] show that iteration of the Zellner procedure until convergence yields maximum likelihood estimated which is invariant to the choice of equation deleted. The estimated cost function is a multi-input, non-homothetic function, which allows for non-constant returns to scale, non-neutral technical progress and variable elasticity of substitution.

Table 1: Model Estimates

	Textile-2297 Variable	
Parameter	**Coefficient**	**t-statistics**
□ □	-14.779	-6.71***
□e	0.088	6.87***
□m	0.501	5.15***
□l	0.588	10.82***
□k	-0.177	-1.88**
□q	6.511	7.99***
□t	-0.338	-5.48***
□ee	0.019	6.38***
□mm	0.031	1.18
□ll	0.144	3.67***
□kk	-0.010	-0.58
□qq	-1.003	-6.61***
□em	-0.011	-1.64*
□el	-0.006	-1.46
□ek	-0.002	-1.05
□ml	-0.049	-2.52***
□mk	0.028	1.78*
□lk	-0.017	-1.86**
□eq	-0.013	-6.79***
□mq	0.003	0.15
□lq	-0.060	-6.44***
□kq	0.070	3.93***
□qt	0.061	5.25***
□et	0.001	11.09***
□mt	0.000	-0.01
□lt	0.001	1.38
□kt	-0.002	-1.76*
□tt	-0.004	-4.34***
Adjusted R^2	0.999	

Note: *** significant at the 0.01level; ** significant at the 0.05 level; and * significant at the 0.10 level.

Table 2: Econometric Results: Substitution Elasticities, Scale Economies and Technical Change

SIC 2297	**Substitution Elasticities**						**Scale Economies**	**Technical Change**
Year	$\sigma\varepsilon\mu$	$\sigma\varepsilon\iota$	$\sigma\varepsilon\kappa$	$\sigma\mu\iota$	$\sigma\mu\kappa$	$\sigma\iota\kappa$	**SE**	**TC**
1958	0.093	-0.122	0.686	0.603	1.244	0.689	1.121	0.012
1959	0.089	-0.227	0.711	0.567	1.224	0.689	1.231	0.018
1960	0.091	-0.273	0.686	0.576	1.230	0.668	1.341	0.025
1961	0.098	-0.273	0.691	0.572	1.228	0.668	1.371	0.027
1962	-0.026	-0.446	0.683	0.552	1.216	0.687	1.392	0.028
1963	-0.031	-0.528	0.676	0.543	1.213	0.675	1.236	0.019
1964	0.074	-0.458	0.666	0.557	1.223	0.638	1.287	0.022
1965	0.002	-0.432	0.641	0.581	1.231	0.658	1.202	0.017
1966	-0.025	-0.481	0.513	0.627	1.270	0.598	1.131	0.013
1967	0.016	-0.518	0.620	0.577	1.233	0.631	1.143	0.015
1968	-0.169	-0.552	0.667	0.550	1.213	0.709	1.097	0.012
1969	-0.227	-0.760	0.596	0.565	1.219	0.676	0.999	0.007
1970	-0.148	-0.821	0.616	0.542	1.212	0.653	1.030	0.009
1971	-0.266	-1.240	0.445	0.571	1.234	0.574	0.869	0.000
1972	-0.241	-0.837	0.635	0.530	1.205	0.687	0.805	-0.004
1973	-0.107	-0.630	0.668	0.535	1.208	0.684	0.969	0.006
1974	0.150	-0.507	0.737	0.482	1.198	0.638	0.982	0.007
1975	0.198	-0.398	0.715	0.523	1.214	0.616	0.953	0.006
1976	0.157	-0.506	0.763	0.450	1.190	0.650	0.886	0.001
1977	0.279	-0.411	0.779	0.441	1.193	0.612	0.721	-0.009
1978	0.231	-0.494	0.787	0.411	1.185	0.631	0.509	-0.021
1979	0.256	-0.556	0.786	0.394	1.183	0.606	0.552	-0.018
1980	0.316	-0.433	0.804	0.388	1.184	0.604	0.569	-0.017
1981	0.376	-0.364	0.825	0.359	1.181	0.592	0.592	-0.015
1982	0.458	-0.116	0.827	0.425	1.197	0.584	0.761	-0.005
1983	0.468	-0.030	0.849	0.406	1.191	0.619	0.791	-0.003
1984	0.425	-0.097	0.841	0.407	1.189	0.628	0.804	-0.002
1985	0.411	-0.062	0.838	0.428	1.193	0.643	0.903	0.005
1986	0.385	-0.015	0.839	0.443	1.194	0.670	0.946	0.007
1987	0.489	0.077	0.851	0.440	1.199	0.630	0.726	-0.005
1988	0.458	-0.080	0.858	0.365	1.184	0.622	0.608	-0.012
1989	0.471	-0.102	0.850	0.375	1.187	0.600	0.646	-0.009
1990	0.423	-0.188	0.851	0.348	1.180	0.618	0.724	-0.005
1991	0.439	-0.133	0.851	0.366	1.183	0.619	0.847	0.003
1992	0.480	0.032	0.840	0.448	1.201	0.615	0.890	0.005
1993	0.483	0.024	0.855	0.410	1.193	0.626	0.897	0.006
1994	0.489	0.105	0.865	0.415	1.194	0.651	0.827	0.002
1995	0.485	-0.066	0.830	0.431	1.200	0.574	0.820	0.002
1996	0.432	-0.068	0.854	0.383	1.185	0.641	0.937	0.009
Means	0.205	-0.333	0.746	0.477	1.205	0.638	0.926	0.004

NOTES