WOOL AND SYNTHETICS:
A Statistical Analysis of Fibre Substitution in the U.S.

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1. *Introduction*

Competition between textile fibres has become very intense in recent years. Non-cellulosic synthetics have established themselves as powerful competitors with wool in a relatively short space of time. This development has been accompanied by substantial gains in incomes and population in those countries where wool has suffered the most serious set-backs. Of these, the U.S., being both the prime mover and pacesetter in the adoption of synthetic fibres, has caused the most serious concern to wool-producing communities.

Several studies have appeared recently attempting to assess the strength of the forces adverse to wool. The survey work undertaken by the Bureau of Agricultural Economics has been particularly valuable in appraising the various qualitative factors influencing the production and use of synthetic fibres.[1] For the purpose of econometric analysis, two approaches to the problem of inter-fibre competition appear practicable, and have been employed recently. One is to focus on inter-fibre substitution at the mill level. This "derived demand" method presupposes that the changes in raw fibre usage consequent upon the development of a new fibre are essentially technologically determined, being subject to acceleration by changes in the prices of raw fibres and possibly by the intensity of promotion of various competing fibres.[2] This approach has considerable appeal on two grounds. First, it measures the direct impact of changing relative prices upon the growth pattern underlying the adoption of a new product. Second, in the early stages of technological development of new textile materials, it is essentially the manufacturers' initiative rather than consumers' choice between alternative textile fibres which governs the pattern of fibre usage. Nevertheless, the most important reason for using this method of analysis arises from deficiencies of published textile data. At present, only the U.S. and Japan publish adequate information on fibre composition in various end-uses. If we wish to study fibre consumption trends in other coun-

* This paper has been prepared under the Post-graduate Program in Wool Economics Research at the University of Adelaide.

[1] See B. A. E. *Wool Consumption Trends in Western Europe and the United States,* Wool Economic Research Report, No. 3, January 1961; and B.A.E., *Competition Between Fibres,* July, 1959.

[2] See A. Powell, M. Polasek and H. T. Burley, "Synthetic Fibres in the Wool Textile Industry: A Study of the Role of Price in Technological Adjustment", *Australian Journal of Agricultural Economics,* Vol. 7, No. 2 (December, 1963), pp. 107-120, and C. E. Ferguson and M. Polasek, "The Elasticity of Import Demand for Raw Apparel Wool in the U.S.", *Econometrica,* Vol. 30, No. 4 (October 1962), pp. 670-699.

tries, the use of manufacturing inputs of various raw fibres is a matter of necessity rather than choice.

The second approach utilizes the existing statistical information on the fibre composition of individual products emerging at the end of the textile manufacturing process.[3] Its main advantage is that it forms a basis for a cross-sectional analysis of a wide range of final textile products, and as such it is more useful for our understanding of the forces responsible for the displacement of wool.

The aim of the present paper is to quantify the trends against wool for a fairly large range of end-products. Accordingly, our attack is along the lines of the second approach mentioned. This task is essentially one of description.

In order to facilitate an orderly and succinct description, we have had recourse to a number of statistical techniques. The basic tool, however, is the logistic growth function, which we have fitted individually to 33 end-uses as well as to aggregate final demand and mill consumption data.

2. *Trends in Wool's Market Shares: Individual End-Uses*

The scope of the present study is restricted to the impact of a specific group of man-made fibres, namely non-cellulosic synthetic fibres, upon wool usage in those textile end-uses in which wool has traditionally been strong.[4] Non-cellulosics have been singled out because of their undisputed wool-displacing potential in virtually all wool-type products. This is not to say, however, that the competitiveness of other fibres with wool is an entirely negligible factor. In the U.S. wool has lost considerable ground to cotton, and to a lesser degree, to rayon—notably in men's slacks and light-weight suits. However, an evaluation of the trends in the market shares of all competing fibres for the entire range of end-uses would be computationally arduous. Also, in the initial stages of the enquiry non-cellulosic fibres are of more interest, for their impact has been felt over a much wider area of textile products.

End-Use Categories Investigated in the Present Study

The data on which this study is based have been derived from the surveys of fibre consumption in various end-uses published annually in *Textile Organon.* These data make no allowance for imports and exports of finished textile products, nor for inventory changes at the retail level, and thus do not reflect accurately actual consumption of fibres in

[3] F. H. Gruen and A. M. Coutts, "An Analysis of Changes in U.S. Wool Consumption", *Australian Journal of Agricultural Economics,* Vol. 5, No. 2 (December 1961), pp. 93-112; and E. L. Jenkins and R. J. O'Toole, "Wool in Clothing: U.S.A. and Japan", *Quarterly Review of Agricultural Economics,* Vol. 16, No. 1 (January 1963), pp. 20-27.

[4] The essential characteristic of non-cellulosics, as distinct from cellulosic materials such as viscose rayon, is that they are produced by polymerization of chemical substances derived from coal and petroleum oil; in less technical language they may be said to be made by the "process of making plastics". They appear in the market under a variety of brand names. Among the most important are: polyamide nylon, the polyesters Dacron and Terylene, the acrylics Orlon, Acrilan and Courtell. For further information on the nature and characteristics of these materials see D. C. Hague, *The Economics of Man-Made Fibres,* G. Duckworth and Co. Ltd., London, 1957, pp. 15-130; and the Bureau of Agricultural Economics, and Department of Trade (Industries Division), *The Australian Wool Textile Industry and Its Use of Wool and Other Fibres,* Industry Study Series, Canberra, 1961.

specific end-uses. This appears to be particularly true of a number of important items which are extensively imported—sweaters, regular weight suits, blankets and some others. On the other hand, the method of collecting the *Textile Organon* data does not ensure that double counting of some fibre inputs is completely avoided. For instance, wool discarded on the worsted system on account of insufficient quality and staple may again be used in the manufacture of woollen materials. As a result of double counting and inclusion of non-virgin wool, the *Textile Organon* estimates of end-use consumption tend to exceed domestic mill consumption (adjusted for imports of wool semi-manufactures) by some 20-25 per cent each year.[5] However, these overestimates are somewhat offset by the exclusion of finished wool articles imported into the U.S. Despite their shortcomings, the *Textile Organon* estimates are the best currently available for our purpose and must be accepted as such, albeit with some caution.

The end-use items selected for analysis are those which individually absorbed more than 50,000 pounds of wool during each year included in the data. To reduce the number of categories for computational purposes, some end-uses with low wool poundage have been amalgamated in accordance with certain common characteristics. For instance, work shirts, sports shirts, and knit sports shirts, have been combined into one category. In all, 33 end-use categories have been selected for analysis, with wool consumption ranging from about 0·5 million pounds annually in anklets and gloves, to an annual consumption exceeding 60 million pounds in women's coats.

Textile Organon classifies all end-use data into six broad groups of products: Men's and Boys', Women's and Misses', Children's and Infants' Wear, Home Furnishings, Other Consumer Uses, and Industrial Uses. Some apparel end-uses, such as sweaters, topcoats and overcoats, and slacks, are tabulated separately for each group. This cross-classification has been retained here to enable comparisons of fibre-usage trends between various apparel items bought by consumers.

Method of Trend Fitting and Analysis of Predicting Error

Non-cellulosic materials capable of displacing wool in textile manufacture are a relatively new product. In the U.S. they first appeared on a commercial scale in the late 1940's. They have since become firmly established as wool substitutes in a great many uses, so much so that in recent years the tonnage of synthetics consumed by the U.S. textile industry annually has been roughly equal to that of virgin raw wool.

The process by which a new product gains widespread acceptance is not an even one. In the initial development stage the innovational impact upon traditional products is negligible, but as the new product is gradually assimilated into the fabric of existing substitutes, its rate of adoption shows signs of acceleration until a point of inflexion is reached beyond which the increments of growth decline, although the direction of growth still remains positive. The last phase in this dynamic process of market adjustment is one of relative stability. The original innovational impetus having lost much of its force, the growth potential of the new product diminishes, though without ever reaching zero. In the absence of a further technological break-through, this last phase may be interpreted as the period of restoration of the long-run market equilibrium.

[5] *Textile Organon*, Vol. 33, No. 11 (November 1962), p. 207.

When we are dealing with inter-fibre competition involving man-made synthetics it is evidently the impact of technological change upon fibre usage which is of greatest interest. The standard technique in such a situation is to fit to the observed data a trend function whose parameters give some indication of the speed of adjustment in the market and also of the ceiling that the new product may be expected to reach if the present technical and market conditions continue to exist. It should be clearly realized, however, that this statistical procedure amounts to no more than a description of the general movement in the observed series.[6]

Within the complex textile industry, producing a large variety of products with many different characteristics and uses, the pattern of adoption of the new fibres will evidently not be uniform in all areas. Furthermore, judging by our experience of fitting price-accelerated trends to U.S. data, the "technological" factors are of overwhelming importance in accounting for the changing pattern of fibre usage in the U.S.[7] We have, therefore, devoted our main effort to the fitting of pure trend functions to end-use data.

We define the variable y_{it} as the ratio of consumption of non-cellulosic staple and yarn to consumption of wool plus non-cellulosic staple and yarn in the i^{th} end-use, in period t.[8] For the lack of a better term, this ratio will be referred to henceforth as synthetics' "share of the market" even though this term may be somewhat misleading for a number of items which absorb other fibres, such as rayon and cotton, in significant quantities. The logistic growth function which is assumed to describe the series y_{it}, apart from random disturbances, has the mathematical form

$$y_{it} = K_i/\{ 1 + e^{-(a_i + b_i t)}\} ,$$

where y_{it} is the trend value of synthetics' share of the market for the i^{th} end-use, K_i is the ceiling content of synthetics in the i^{th} end-use, a_i is a coefficient situating the logistic on the time scale, and b_i is a measure of the rate of adoption of synthetics in the i^{th} end-use. One property of the logistic is that it is asymptotic to 0 and K_i. Our definition of y_{it} does not allow K_i to exceed unity, for the synthetics content of any individual item cannot exceed 100 per cent. The method of fitting followed in this study utilizes the transformation of the logistic into an equation linear in the parameters a_i and b_i.[9]

[6] A model which would account for the influence of measurable economic stimuli upon the underlying "technological trend" is more difficult to construct. For an attempt to fit price-accelerated trends by expressing the rate of adoption and the ultimate absorption ceiling of synthetics in the U.S. as a function of the relative prices of wool and synthetics, see A. Powell, M. Polasek, H. T. Burley, *op. cit.* The major conclusion of this prior study was that the role of price in the adjustment of the U.S. textile market to synthetic substitutes has been of minor importance.

[7] Powell, Polasek and Burley, *op. cit.*

[8] The non-cellulosic data include quantities of textile glass fibre as these are not separated in *Textile Organon.*

[9] This method was proposed and used by Zvi Griliches, "Hybrid Corn: An Exploration in the Economics of Technological Change", *Econometrica,* Vol. 25, No. 4 (October 1957), pp. 501-522. By dividing both sides of the logistic by $(K - y)$, the transform $ln\{y/(K - y)\} = a + bt$ is obtained, and in this form the parameters can be estimated by least-squares. The use of a high-speed computer enabled the ceiling value K to be varied in small steps with the least-squares estimates of the logistic transform iterated until minimum residuals were obtained, or (in certain cases) until other criteria were satisfied. See the Appendix.

The most commonly used measure of the "goodness of fit" of a statistically fitted curve is the coefficient of multiple determination, R^2. In the case of a linear function fitted by least-squares, this measure indicates the proportion of the total variance of the regressand accounted for by the fitted relation. The balance is attributed to "error". However, where non-linear relations are fitted, this additivity property no longer necessarily holds. This is due to the possibility that predicting error may be correlated (positively or negatively) with predictions made by using the fitted relation, a circumstance which cannot occur in the case of a linear model fitted by least-squares. To measure the strength with which the data adheres to the fitted logistic trends, we have computed the ratio (sum of squares due to fitted curve)/(total sum of squares), and labelled the result "quasi-R^2". The interpretation is much the same as that of an ordinary R^2 except in those cases where the correlation between predictions and predicting errors has considerable absolute magnitude. The size of the effect due to such correlations is indicated in Table 2.

Traditional correlation analysis has, however, one important disadvantage in that perfect correlation does not necessarily mean that the fitted relationship will always yield perfect forecasts. An alternative analysis of predicting error has been suggested by Theil.[10] He has proposed the use of a coefficient of inequality between the predicted and actual series defined by

$$U = \left[\sum_{t=1}^{N}\left(\hat{y}_t - y_t\right)^2 \Big/ N\right]^{\frac{1}{2}} \Bigg/ \left\{\left[\sum_{t=1}^{N} \hat{y}_t^2 \Big/ N\right]^{\frac{1}{2}} + \left[\sum_{t=1}^{N} y_t^2/N\right]^{\frac{1}{2}}\right\}$$

This measure becomes zero if the estimated values coincide with the corresponding actual outcomes. When $U = 1$, the actual values and predictions reach the maximum degree of inequality. The square of U can be decomposed into three components of inequality, $U^2{}_M$, $U^2{}_S$ and $U^2{}_C$, measuring respectively the discrepancy between the means and variances of the observed and predicted series, and the failure of the observations to correlate perfectly with predictions.

Expressing these partial coefficients of inequality as proportions and designating them as U^M, U^S and U^C, the relative contribution due to each of the three sources of inequality can be calculated. If the predictive properties of the model fall short of perfection, it is desirable at least that the distribution of the three sources of inequality should be such that "systematic" forecasting errors are avoided. This is to say that the source of inequality U^M attributable to a bias resulting from unequal central tendency in the predicted and actual values should be zero or very small, and the same should be true of the component U^S measuring the contribution to inequality made by unequal variances. As a consequence, the element U^C should be in the close vicinity of one.[11] In the present study this requirement has been met fairly successfully in a majority of cases.

Results of Statistical Analysis of End-Use Data

A summary of the results classified according to their conformity to a logistic pattern of growth and the height of their absorption asymptote

[10] H. Theil, *Economic Forecasts and Policy,* North Holland, Amsterdam (second edition), 1961, pp. 31-48.
[11] See Theil, *op. cit.*, p. 37.

is presented in Table 1. Table 2 gives the results of the analysis of predicting error.

In order to understand better a body of data such as this, one ideally would wish to run a cross-sectional analysis on the results with a view to ascertaining what factors have contributed significantly to the differential impact of synthetics in the various sectors of the market. However, such factors are not, for the most part, amenable to quantification; and in any event, it is doubtful whether a model which would provide an essentially economic interpretation of the differences in the coefficients could be formulated at all. We must rely on considerations of a more general nature to provide at least part of the explanation.

It will be noted first that the results generally lend support to our choice of the logistic trend function. Only in four end-uses is the fit very poor, but in all four cases the nature of the product is such that a weak and irregular fibre substitution effect could be expected.[12]

The results are satisfactory enough on statistical grounds to shed some light on questions such as whether the frequently reported trends towards casual, easy-care clothing and lighter weight materials generally, tend to favour synthetic fibres relative to wool; or, whether there is some evidence of differential rates of adoption and ceiling values between the various broad classes of wool products, and particularly between men's, women's, and children's apparel items. From the information in Table 1 we are also able to determine the extent of the inroads made by synthetics into end-uses which rank high in importance by virtue of the wool tonnage absorbed in them.

As far as can be gathered from the tabulated results, those items of apparel which are suited for casual wear conform closely to the assumed market adjustment trend and also have high or intermediate ceiling values; the only exception is Women's Slacks and Jackets. The items Men's Workshirts and Sportshirts (the latter have a much heavier weight within this category than the former), Women's and Children's Sweaters, and Teenage and Children's Slacks all have ceiling values in excess of 80 per cent. Men's Separate Slacks, and Sweaters, appear to be less susceptible to encroachment by man-made substitutes than the preceding four items, but the ceiling value in Separate Slacks, an important item, augurs substantial ultimate displacement of wool. It may seem surprising to find all the sweater items in a group where competition with non-cellulosics is intense. But it has been the U.S. experience that in knit-wear wool has been seriously challenged by acrylic fibres, notably Orlon, so much so that acrylics have probably displaced more wool than nylon and the polyesters together.[13]

As for the alleged trend towards lighter-weight fabrics, nothing definite can be gleaned from the data processed in this study, except perhaps that in Light and Midweight Suits, the ultimate ceiling content of synthetics can be expected to lie above 50 per cent; once more, the evidence points to significant wool displacement.

The differences between the estimated coefficients over the six main

[12] These are: Men's Regular Weight Suits, Men's Overcoats and Topcoats, Men's (Civilian and Athletic) Uniforms and Outdoor Jackets, and Women's Slacks and Jackets. The reason for the weakness of the substitution effect in the last end-use is perhaps due to the predominance of heavy winter-wear garments included in this category.

[13] B.A.E., *Wool Consumption Trends in Western Europe and the United States,* Wool Economic Research Report No. 3, January 1961, p. 27.

TABLE 1

Estimates of Logistic Trends in 33 Wool End-Uses: U.S. Annual Data, 1949-61

Category*	Type of Estimate†	Estimates of: Ceiling K	Origin-fixing Parameter a	Rate of Adoption, b	Quasi-R^2‡	Mean Wool Consumption 1949-61	
Group I. High Correlation, High Ceiling ($R^2 \geqq 0{\cdot}90$; $K > 0{\cdot}80$)						million lb.	per cent
M: Workshirts, sportshirts (woven) and sportshirts (knit)	MCP	0·892	—3·092	0·384	0·94	10·2	1·8
W: Sweaters	LS	0·870	—2·148	0·405	0·94	13·6	2·4
W: Blouses and shirts	LS	1·000	—0·668	0·227	0·95	3·3	0·6
W: Anklets, sox and gloves	LS	0·942	—0·850	0·393	0·95	0·6	0·1
C. Sweaters	LS	0·830	—4·306	0·785	0·98	3·2	0·6
C: Slacks, slack-suits and outer outwear	RLS	0·880	—4·169	0·377	0·98	3·1	0·6
F: Upholstery, drapery	LS	0·993	—3·048	0·784	0·91	1·9	0·3
O: Apparel linings	RLS	0·914	—5·087	0·695	0·98	4·8	0·9
I: Transportation upholstery	RLS	0·918	—3·936	0·661	0·97	14·2	2·5
Group II. High Correlation, Intermediate Ceiling ($R^2 \geqq 0{\cdot}90$; $0{\cdot}20 < K \leqq 0{\cdot}80$)						million lb.	per cent
M: Light and midweight suits	LS	0·545	—2·715	0·545	0·94	5·5	1·0
M: Separate slacks	MCP	0·589	—3·267	0·439	0·98	21·9	3·9
M: Sweaters	LS	0·380	—4·192	0·628	0·98	16·1	2·9
M: Robes, smoking jackets and ties	LS	0·345	—5·815	0·559	0·97	3·8	0·7
M: Hose—all types	RLS	0·691	—0·542	0·259	0·93	8·6	1·5
W: Playsuits, shorts and loungewear	LS	0·649	—2·367	0·511	0·98	2·0	0·3
F: Blankets and blanketing	MCP	0·750	—6·104	0·740	0·97	16·7	3·0
O: Retail piece-goods	MCP	0·340	—3·544	0·516	0·97	16·9	3·0
I: Felts	RLS	0·270	—3·824	0·436	0·96	10·1	1·8
Carpets, rugs (total)	MCP	0·420	—7·319	0·732	0·96	140·5	25·0

[continued overleaf]

* End-use categories are cross-classified as follows:
M: Men's and Boys' Wear
W: Women's, Misses' and Juniors' Wear
C: Teenage, Girls', Children's and Infants' Wear
F: Home Furnishings
O: Other Consumer-type Goods
I: Industrial Uses

† LS indicates K estimated by (indirect) least-squares. For details of other types of estimates, see Appendix

‡ The ratio of the sum of squares due to the fitted trend to the variance of the series

TABLE 1 (continued)

Estimates of Logistic Trends in 33 Wool End-Uses: U.S. Annual Data, 1949-61

Category*	Type of Estimate†	Estimates of: Ceiling K	Origin-fixing Parameter a	Rate of Adoption, b	Quasi-R^2‡	Mean Wool Consumption 1949-61	
Group III. High Correlation, Low Ceiling ($R^2 \geqq 0{\cdot}90$; $K \leqq 0{\cdot}20$)							
						million lb.	per cent
W: Suits	LS	0·114	—2·527	0·422	0·92	15·7	2·8
W: Coats	MCP= LS	0·097	—4·852	0·654	0·96	65·0	11·6
C: Coats, jackets etc.	MCP= LS	0·113	—3·377	0·441	0·92	18·1	3·2
Group IV. Low Correlation, High Ceiling ($R^2 < 0{\cdot}90$; $K > 0{\cdot}80$)							
C: Dresses	RLS	1·000	—1·299	0·334	0·79	0·4	0·0
Group V. Low Correlation, Intermediate Ceiling $R^2 < 0{\cdot}90$; $0{\cdot}20 < K \leqq 0{\cdot}80$							
M: Tailored civilian uniforms, athletic uniforms, o/door jackets	LS	0·320	—0·971	0·073	0·16	32·9	5·9
M: Underwear (knit)	MCP	0·670	—1·203	0·150	0·68	1·8	0·3
W. Unit-priced dresses	RLS	0·610	—0·149	0·086	0·62	16·7	3·0
O: Handwork yarns	LS	0·216	—1·458	0·360	0·82	0·8	0·1
Group VI. Low Correlation, Low Ceiling ($R^2 < 0{\cdot}90$; $K \leqq 0{\cdot}20$)							
						million lb.	per cent
M: Regular weight suits	LS	0·026	0·205	0·137	0·09	46·9	8·4
M: Separate coats, tailored	RLS	0·140	—2·562	0·261	0·75	13·6	2·4
M: Overcoats, topcoats	RLS	0·055	—2·739	0·177	0·39	17·7	3·2
W: Skirts	MCP	0·119	—1·233	0·210	0·61	24·4	4·4
W: Slacks and jackets	LS	0·051	—0·513	0·162	0·14	6·6	1·2
C: Suits and skirts	MCP	0·152	—1·840	0·245	0·67	3·2	0·6

* End-use categories are cross-classified as follows:
M: Men's and Boy's Wear
W: Women's, Misses' and Juniors' Wear
C: Teenage, Girls', Children's and Infants' Wear
F: Home Furnishings
O: Other Consumer-type Goods
I: Industrial Uses

† LS indicates K estimated by (indirect) least squares. For details of other types of estimates, see Appendix

‡ The ratio of the sum of squares due to the fitted trend to the variance of the series.

TABLE 2

Analysis of Predicting Error:
Logistic Trends Fitted to 33 Wool End-Uses
U.S. Annual Data, 1949-61

Category	Partition of Variance: Proportions of Variance due to: Trend	Error	Cross-pdct.	Coefficient of Inequality	Analysis of Inequality: Proportions of Inequality due to: Bias,	Variance,	Covariance
			Group I.	U	U^M	U^S	U^C
M: Workshirts, sportshirts, etc.	1·127	0·078	—0·205	0·073	0·004	0·048	0·948
W: Sweaters	0·894	0·062	0·044	0·055	0·015	0·049	0·936
W: Blouses and shirts	0·958	0·045	—0·003	0·025	0·001	0·009	0·990
W: Anklets, sox and gloves	0·989	0·050	—0·039	0·027	0·002	0·001	0·997
C: Sweaters	1·010	0·017	—0·027	0·030	0·005	0·001	0·994
C: Slacks, slack-suits, etc.	1·015	0·034	—0·049	0·053	0·001	0·001	0·998
F: Upholstery drapery	0·823	0·082	0·095	0·062	0·062	0·112	0·826
O: Apparel linings	1·026	0·023	—0·049	0·035	0·052	0·006	0·942
I: Transportation upholstery	0·910	0·024	0·066	0·043	0·011	0·088	0·901
			Group II.				
M: Light and midweight suits	0·947	0·060	—0·007	0·050	0·058	0·014	0·928
M: Separate slacks	1·083	0·017	—0·099	0·034	0·040	0·096	0·864
M: Sweaters	1·011	0·023	—0·034	0·042	0·077	0·001	0·922
M: Robes, smoking jackets, etc.	0·988	0·026	—0·014	0·048	0·001	0·001	0·988
M: Hose—all types	0·972	0·071	—0·043	0·029	0·003	0·003	0·994
W: Playsuits, shorts, etc	0·964	0·015	0·021	0·025	0·025	0·022	0·953
F: Blankets and blanketing	1·100	0·030	—0·130	0·050	0·124	0·073	0·803
O: Retail piece-goods	1·035	0·035	—0·073	0·049	0·104	0·009	0·887
I: Felts	0·914	0·035	0·051	0·059	0·031	0·056	0·913
Carpets, rugs	1·108	0·051	—0·159	0·072	0·000	0·054	0·946
			Group III.				
W: Suits	0·907	0·074	0·019	0·066	0·027	0·032	0·941
W: Coats	0·908	0·030	0·062	0·042	0·000	0·075	0·925
C: Coats, jackets etc.	1·049	0·095	—0·144	0·084	0·005	0·006	0·989
			Group IV.				
C: Dresses	0·661	0·166	0·173	0·077	0·015	0·215	0·770

[concluded overleaf]

TABLE 2 (continued)

Analysis of Predicting Error:
Logistic Trends Fitted to 33 Wool End-Uses
U.S. Annual Data, 1949-61

Category	Partition of Variance — Proportions of Variance due to: Trend	Error	Cross-pdct.	Coefficient of Inequality U	Analysis of Inequality — Proportions of Inequality due to: Bias, Variance, Covariance U^M	U^S	U^C
Group V.							
M: Tailored civilian uniforms etc.	0·160	0·828	0·012	0·179	0·002	0·437	0·561
M: Underwear (knit)	0·734	0·344	—0·078	0·076	0·000	0·060	0·940
W: Unit-priced dresses	0·589	0·363	0·049	0·048	0·000	0·150	0·850
O: Handwork yarns	0·780	0·172	0·048	0·077	0·000	0·080	0·920
Group VI.							
M: Regular weight suits	0·092	0·893	0·015	0·149	0·006	0·559	0·435
M: Separate coats, tailored	0·719	0·234	0·047	0·128	0·008	0·105	0·887
M: Overcoats, topcoats	0·555	0·399	0·046	0·165	0·023	0·171	0·806
W: Skirts	0·693	0·434	—0·127	0·121	0·000	0·065	0·935
W: Slacks and jackets	0·131	0·821	0·048	0·134	0·027	0·545	0·428
C: Suits and skirts	0·718	0·355	—0·073	0·085	0·000	0·065	0·935

groups of textile products are somewhat more difficult to explain. Men's apparel items appear to be concentrated most heavily in the intermediate ceiling group and in the low ceiling group. In some items, such as Light and Midweight Slacks and Separate Slacks, this may possibly be attributed to the practice of blending wool with synthetics. In others, where the fit is particularly poor, this finding seems to indicate that the process of adoption of synthetics in men's apparel lines has been less regular than implied by our model, possibly because men are more conservative in their clothing habits and less willing to experiment than women. A study of various reports surveying the attitude of consumers to different fibres would no doubt throw further light on this question but this would extend the scope of this paper beyond our present purpose.

On the other hand, the "femininity" factor helps little to explain why the response to synthetics varies markedly over the whole range of women's apparel articles covered by *Textile Organon*. Rather, the resistance (or otherwise) of any individual apparel item to wool's synthetic substitutes seems to be guided by the nature of the product. As can be seen, the displacement potential of wool in sweaters, blouses and shirts is high, somewhat weaker in unit-priced dresses, and very weak in a number of items such as suits, coats, skirts, and slacks and jackets. Teenage and children's wear likewise fail to follow any discernible pattern.

However, all the non-apparel end-uses investigated adhere closely to the postulated trend pattern, and furthermore, their ceiling asymptotes are high or in the intermediate range. This confirms the findings of other studies[14] which also point out that wool has been dislodged almost completely from Draperies and Upholstery, as well as Transportation Upholstery, and has suffered significant set-backs in Blankets, Carpets, and to a lesser extent, in Felts and various Piece Goods. The tabulated results give an indication of the limiting ceiling values which are likely to be reached in these end-uses under present conditions of textile technology.

Lastly, it is of interest to consider whether there appears to be any association between the estimated coefficients and the contributions made by individual end-uses to wool poundage absorbed in wool textile manufacture. Mean wool consumption in each end-product, calculated over the period 1949-1961, is a reasonably satisfactory measure for that purpose. Comparing the results in Table 1, we observe that Group I comprises items mostly of relatively minor importance in terms of wool poundage consumed. The end-uses with ceilings in the intermediate range, including those with low correlations, clearly account for the bulk of wool consumption, and the items which have rather low asymptote values, too, account for a significant proportion of the mean wool poundages shown in Table 1.

These comparisons suggest that even though wool may have lost a good deal of ground to synthetics in the last decade or so, synthetics' share of the market in a number of textile products which really matter on account of their large weight in aggregate wool consumption, are likely to settle at not too high ceiling values. In the absence of changes which would further revolutionize textile technology, the worst seems to be over for a number of end-uses in which synthetics have made rapid advances since 1949. As for the important apparel items in which wool has so far been successful in resisting non-cellulosic fibres—Women's Suits, Coats, Skirts, Men's Regular Weight Suits and Separate Jackets—there do not seem to be any strong reasons why wool should not continue to hold its ground on the strength of its intrinsic properties as a fibre. On balance, then, the estimated ceiling coefficients for the most important wool-absorbing apparel items lend support to the view that when the process of innovation has worked itself through, wool will still be able to retain a substantial share of the market.

3. *Trends in Wool's Market Shares: Aggregate Basis*

If we wish to carry this sort of analysis to the aggregate level, a new difficulty arises—the index-number problem. The ratio y_t, defined now in terms of aggregates, varies over time not only because synthetics may displace wool in individual end-uses, but also because the structure of output of the wool textile industry may change, for reasons connected perhaps with shifts in consumers' preferences or other autonomous influences on living and housing conditions. For instance, if more regular weight instead of light weight suits are demanded, aggregate wool consumption is likely to rise because the former have, on average, higher wool content than the latter. The effect of this sort of

[14] See particularly F. H. Gruen and A. M. Coutts, *op. cit.*, pp. 100-103; and B.A.E., *Wool Consumption Trends op. cit.*, p. 24.

change on the aggregate ratio y_t has been termed the "fashion effect",[15] as contrasted with the "substitution effect" due to fibre displacement within individual uses. The index-number problem is involved here because in attempting to isolate the fashion effect an ambiguity arises in deciding which period's structure of weights should be used. As it turns out, however, the weighting ambiguity is of small significance for prediction of future aggregate market shares, as will be seen below.

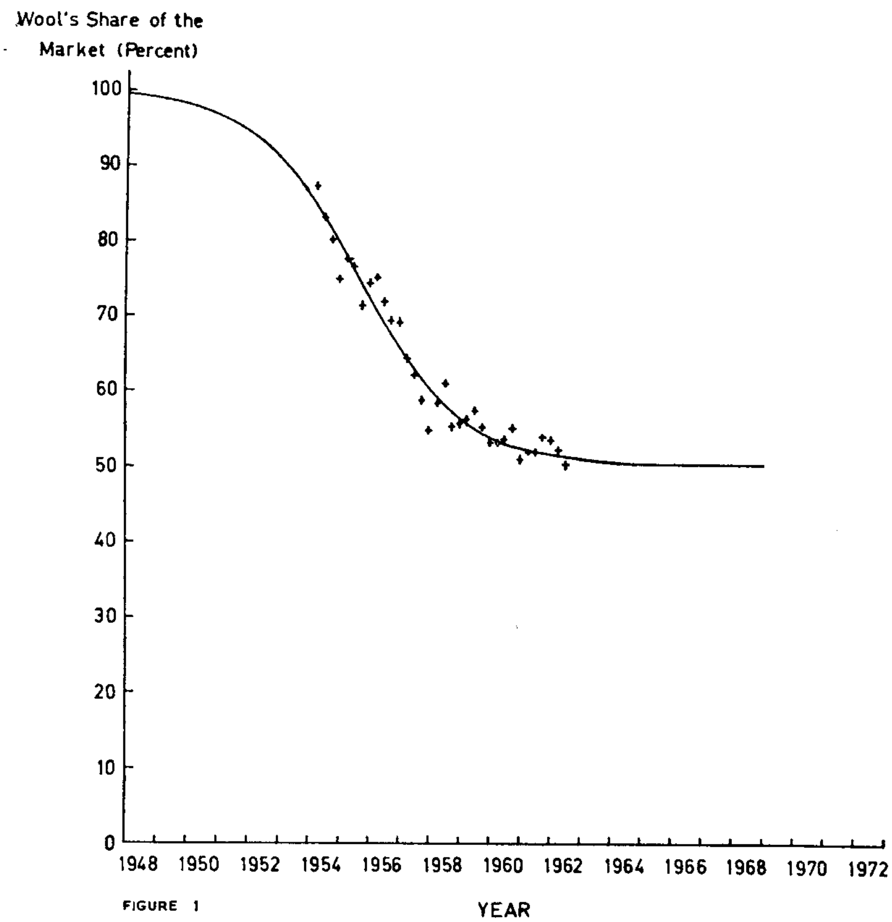

FIGURE 1

Several logistic trends were fitted to aggregate data with rather consistent results. However, since at this stage of the analysis our interest lies more in the limits to wool's potential displacement rather than in synthetics' share of the market, the ratio z_t was defined as $1 - Y_t$, i.e. wool's "share of the market"; the computed coefficients K, a and b appearing in Table 3 should be interpreted accordingly. It can be seen that the ceiling estimates are bunched very closely together, the apparel wool estimates being slightly lower than those obtained from data including carpet wool. All the relationships fit remarkably well, confirming once more the strength of the logistic pattern of innovation.

From the point of view of Australia's interest in the U.S. wool market,

[15] This term appears to have been coined by F. H. Gruen and A. M. Coutts, *op. cit.* p. 94.

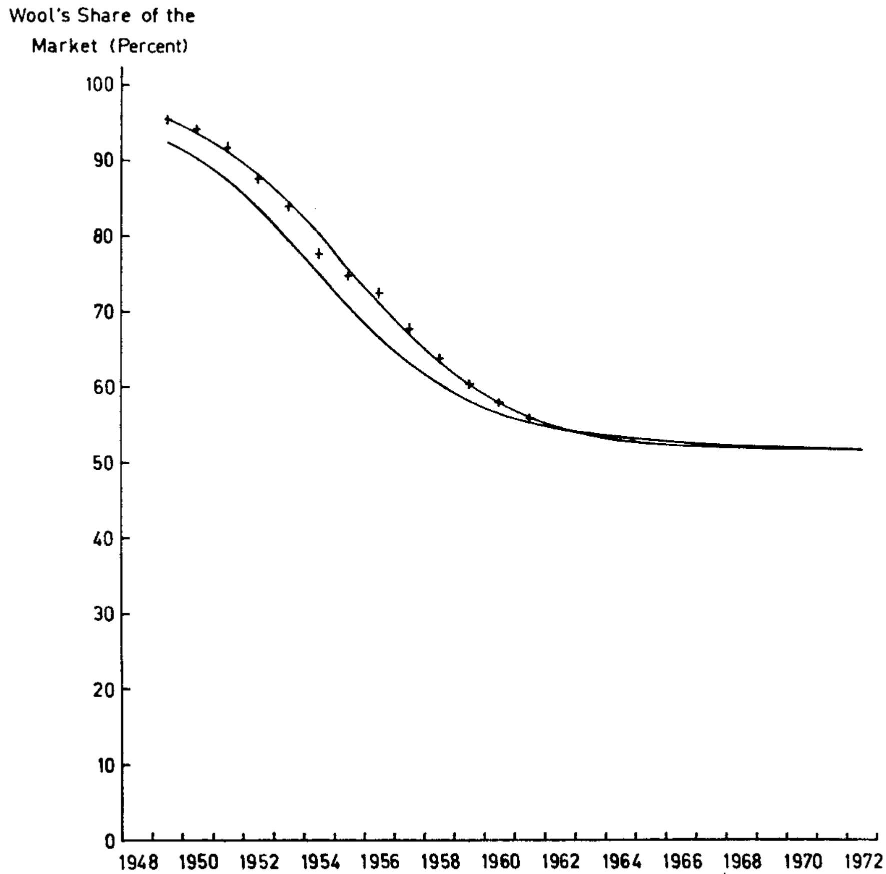

FIGURE 2

those results excluding carpet wool are the most relevant. For the sake of comparison with the results obtained from *Textile Organon* end-use series, we first fitted a logistic trend to *mill* consumption data available on a quarterly basis, and plotted the result of Figure 1. By aggregating these data over four quarters for the years 1954-61, and by changing the time scale so that 1949 = 1, we obtained estimates of the parameters on an annual basis; these appear in Table 3. The computed "floor" values of z_t in the vicinity of 50 per cent in both cases imply that as far as we can tell on the basis of experience up to date, the ultimate displacement of wool will result in as much non-cellulosic staple fibre being consumed in the U.S. mills as (clean) virgin wool. This assumes, of course, that there is no radical change in the fibre market such as might be occasioned if a better substitute for wool were invented.

The results based on *Textile Organon* end-use data and their projections are graphed in Figure 2. The upper curve has been fitted to an estimate of wool's overall 'share of the market', excluding carpet wool, derived by aggregating the data used in the previous section.
The second curve is not a statistically fitted relationship but a hypothetical market adjustment path

$$\hat{z}_{\cdot t} = 1 - \sum_{i=1}^{32} \hat{y}_{it}\, p_i$$

TABLE 3

Estimates of Logistic Trends: Aggregate Basis
U.S. Annual Data, 1949-61

Data fitted (i)	Type of estimate	Estimates of:			
		Ceiling(ii) K	Origin-fixing Parameter, a	Rate of Adoption b	Quasi R^2
Mill consumption data (iii)	LS	0·486	—3·938	0·573	0·981
End-uses aggregated—carpets excluded	LS	0·481	—2·657	0·382	0·995
Aggregate projection based on trends within end-uses—1961 quantity weights—carpets excluded (iv)		0·492	—	—	—
End-uses aggregated—carpets included	LS	0·478	—2·920	0·377	0·995
Aggregate projection based on trends within end-uses—1961 quantity weights—carpets included (iv)		0·474	—	—	—

(i) All variants of the data are computed from wool poundages expressed on clean basis.
(ii) The "ceiling values K imply "floor" values equal to $1 - k$; it is the convergence to the latter values that is shown in Figures 1 and 2.
(iii) Fitted to quarterly data for 1954-1961; non-cellulosic data include staple only. Wool data exclude carpet wool. Parameters a and b are shown on annual basis. Mill consumption data were derived from *Textile Organon* 1954-62, and *Survey of Current Business* 1954-62.
(iv) Trends within end-uses estimated from Table 1.

TABLE 4

Analysis of Predicting Error: Aggregate Basis
*U.S. Annual Data, 1949-61**

Data Fitted	Partition of Variance — Proportions of Variance due to: Trend	Error	Cross-pdct.	Coefficient of Inequality U	Analysis of Inequality — Proportions of Inequality due to: Bias,	Variance,	Covariance
Mill Consumption Data	0·947	0·018	0·035	0·018	0·005	0·039	0·956
End-Uses Aggregated—Carpets excluded	1·017	0·005	—0·022	0·017	0·003	0·014	0·983
End-Uses Aggregated—Carpets included	1·021	0·005	—0·026	0·019	0·002	0·021	0·977

* See footnotes to Table 3.

where $\hat{y}_{it}$ is the predicted market share in the i^{th} end-use, in period t, and p_i is a fixed weight given by the ratio

$$(\text{wool}_i + \text{synthetics}_i)_{1961} \ / \sum_{i=1}^{32} (\text{wool}_i + \text{synthetics}_i)_{1961}$$

The ratio p_i measures the contribution of any individual end-use to aggregate fibre consumption in 1961. We observe that if the structure of wool textile output throughout the period 1949-61 conformed to the 1961 pattern, the market shares of wool would have been generally lower than the observed ratios z_t. This would indicate that the "fashion effect", measured by the gap between the two curves, discriminated against end-uses which are relatively heavy wool users. This is particularly true of a number of items such as Men's Regular Weight Suits, Overcoats and Topcoats, Women's Suits and Coats, etc., all of which have shown markedly diminished tonnages of fibre consumed since 1949. However, the results of our calculations suggest that the strength of the unfavourable fashion effect for all practical purposes has worked itself through.

If we regard the upper curve in Figure 2 as our best estimate of the time path for wool's share of the market, then implicit is the assumption that this curve takes account of trends *between* as well as within end-uses: that is to say, both fashion and substitution effects are assumed to manifest themselves in the aggregate series. On the other hand, the projection made using trends within individual end-uses, and employing 1961 weights, indicates what would happen to wool's market share if inter-product preferences were frozen at their 1961 levels. In other words, the lower curve indicates the consequences to be expected if no further fashion effects occurred beyond 1961.

As may be verified from Table 5, the differences between these two sets of extrapolations are very small, and for practical purposes may be ignored. In short, the unfavourable fashion effect appears to have worked itself out, and its future contribution to wool displacement can be expected to be rather insignificant—only about one percentage point, i.e. 2 per cent of the floor value.

A final point of interest arises out of the difference between the growth coefficients estimated from mill consumption and *Textile Organon* data. The value obtained from the mill consumption series is markedly higher than the other two estimates, and the disparity is too large to be left unexplained. But it will be remembered that the first set of estimates in Table 3 were computed from quarterly data for 1946-51 (adjusted to an annual basis); and also, staple non-cellulosics *only* were included in compiling the estimated market share ratios y_t. Non-cellulosics entered first into inter-fibre competition in the form of filament yarn whose impact was felt more strongly in the early years of the period under review. We thus find that non-cellulosic fibres in all forms captured their first ten per cent of the market in late 1951, while according to the extrapolations graphed in Figure 1, synthetic staples alone would have reached that point more than a year later. Once established on a commercial scale, however, synthetic staples, by virtue of their adaptability to the requirements of wool textile manufacture, have proved to be a much more aggressive competitor with wool than filament yarn. The truth of this is strikingly brought home by examining the pattern of fibre usage in end-uses where synthetics in filament form

TABLE 5

Wool's Aggregate "Share of the Market"— Predictions 1962-75

Year	Simple Aggregate of End-Uses (carpets excluded)	Projection based on Trends within End-Uses: 1961 Quantity Weights (carpets excluded)
	per cent	per cent
1962	54·90	54·90
1963	54·00	54·20
1964	53·37	53·71
1965	52·90	53·33
1966	52·60	53·02
1967	52·38	52·76
1968	52·23	52·55
1969	52·12	52·37
1970	52·05	52·22
1971	52·00	52·08
1972	51·97	51·96
1973	51·95	51·85
1974	51·93	51·76
1975	51·92	51·67
∞	51·90	50·80

played an important role in the early phases of the market adjustment process—Men's Outdoor Jackets, Light and Midweight Suits, Sport-shirts, Separate Slacks, Women's Unit-priced Dresses, Blouses and Shirts, to name the most important apparel uses.[16] It is for these reasons that the growth rates computed from the two sets of data are so far apart.

4. *Conclusion*

The main concern of the preceding analysis has been to document the process of synthetics' adoption in a market which is likely to serve as a prototype for experience elsewhere. In so far as the U.S. market is concerned, the present market shares of the two fibres are not very far from the equilibrium values inherent in the observed series, and from this it would appear that *in the absence of further significant technological advances in the synthetic fibre field,* the era of rapid and substantial wool displacement is over.

Appendix

Method of Fitting the Logistic Trends

As indicated in the text, the logistic's linear transform

$$Y_{it} = ln\ \{y_{it}/\ (K_i - y_{it})\ \} = a_j + b_{jt}$$

was used, For arbitrary K_i, the series $\{Y_{it}\}$ was computed, and regressed on time by least-squares. That value of K_i which yielded the smallest residual sum of squares

[16] The same cannot be said to be true of some non-apparel uses, notably of draperies and upholstery, apparel linings, and to a smaller extent retail piece goods. But in these products wool has always been of marginal use, and if any fibre substitution occurred, it would have been mainly at the expense of cotton and rayon. See *Textile Organon,* Vol. 33, No. 11 (November 1962).

$$S = \sum_{t=1}^{N} (y_{it} - \hat{y}_{it})^2$$

was selected, except in cases where this would result in a serious departure from orthogonality in the partition of the variance of the series $\{y_{it}\}$. The extent of the misclosure between the total sum of squares and the sum of the trend component, $\Sigma\ (\hat{y}_{it} - \bar{y}_i)^2$, and the error component, $\Sigma\ (y_{it} - \hat{y}_{it})^2$, is given by the cross-product term:

$$CP = 2 \sum_{t=1}^{N} (\hat{y}_{it} - \bar{y}_i)\ (y_{it} - \hat{y}_{it});$$

and is due to the occurrence of correlation between predictions and predicting error. A "serious" misclosure was judged to occur whenever the absolute value of CP exceeded 5 per cent of the total sum of squares.

When a least-squares (LS) estimate existed and did not involve a serious misclosure, it was accepted. In other cases where the LS estimate did involve serious misclosure, a restricted least-squares (RLS) estimate was accepted, the constraint being that $|\mathrm{CP}| \leqq 0{\cdot}05$. However, it was not always possible to satisfy the additivity condition even approximately: in some cases no values of K_i existed such that $|\mathrm{CP}| < 5$ per cent. The approach here was to find the local minimum of $|\mathrm{CP}|$ (written MCP) closest to the LS solution (when such existed).