TEXTILE FIBRE SUBSTITUTION AND RELATIVE PRICES

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The elasticity of substitution between textile fibres is investigated within a CES production function in which the fibres are grouped according to degree of substitutability. Disaggregated data for U.S. textile usage in the post-war period are examined and the elasticities estimated are generally above unity. The conclusion is reached that, while technical change and diffusion may have explained changing fibre shares in certain, usually specialized end-uses and contributed to the explanation in others, in most end-uses relative price change has been an important factor.

Introduction

The object of this study was to investigate the relationships, in the U.S.A. from 1949 to 1968, of relative fibre prices and the market shares of different fibres in the textile industry. These relationships are of interest to producers of both natural and man-made fibres. The subject is also of general interest, as a case study of marginal productivity analysis and of substitution between more than two factors of production.

A similar study was attempted on the same data (for an early sub-period) by Powell, Polasek, and Burley [8].[1] They followed Griliches [4] in his pioneering paper on Hybrid Corn, and fitted simple logistic curves to the consumption of synthetic staple in the traditional markets of wool. They then allowed for the effects of price changes on the rate of substitution and the final 'ceiling' but found that the simple logistic trends gave the better fit. They concluded that price had no significant role in competition between new and traditional fibres, but rather that the growth in consumption of the new fibres was 'technically determined'.

Griliches [4] had used the logistic to describe the development of Hybrid Corn penetration in a large number of U.S. districts. He regressed the parameters of the logistic for each district, in a cross-section analysis, on the economic return to the planting of Hybrid Corn. He stated that 'the growth curves serve merely as a summary device, perhaps somewhat more sophisticated than a simple average, but which should be treated in the same spirit'.

The approach in this paper is different from these studies. The use of the logistic or any other time-trend is eschewed, on the ground that the data are sufficiently disaggregated by end-use to ignore technological learning curves beyond the first few years of teething. Instead, it is assumed that the progress of a fibre within an end-use once it has made

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[1] See also Polasek and Powell [9 and 10], and Polasek [11].

the quantum jump of penetrating the end-use, depends primarily and directly on price movements.[2] This assumption is explored and tested below.

The Model

The U.S. textile industry is assumed to be competitive. All firms in the industry have a CES production function,[3] identical in each case apart from a multiplicative 'efficiency parameter'. The production function consists of a fibre part and labour-capital part. The two parts substitute with one another (probably with a very low elasticity of substitution), and together may be subject to non-constant returns to scale over certain ranges of production. Within the labour-capital part there is substitutability between labour and capital. Within the fibre part, where several fibres are distinguished, there is substitutability between 'groups' of fibres, each 'group' consisting of fibres which share an elasticity of substitution equal to or greater than that between the group and other fibres.[4] For example, if only three fibres were competing, the production function for the *i*th firm would be expressed (where the F_j are fibres, K is capital and L is labour):

(1)

$$q_i = A^i\left[k_0(\{k_1F_k^{-r}+[(k_2F_2^{-s}+F_3^{-s})^{-1/s}]^{-r}\}^{-1/r})^{-w}+(\{k_3K^{-t}+L^{-t}\}^{-1/t})^{-w}\right]^{\frac{-v(q_i)}{w}}$$

where it is assumed that $s \leqslant r \leqslant w \geqslant t$.

The number of firms who are potentially 'in' the industry is assumed to be fixed; but they will produce zero output if by producing they would make losses, hence the number actually producing can vary. Each firm maximizes profits and is assumed to be in constant long run equilibrium, subject to 'commercial' error terms in the marginal productivity conditions.

It can be shown[5] that, because this production function has the property of homothetic separability, each group of fibres has a price and quantity index, P_f and F respectively, such that the marginal productivity conditions can be rewritten in terms of these indices.

This has the important implication that the ratio of the two fibres inside the group (in this case F_2 and F_3) is fixed independently of the ratio of the group to the other fibre.

It follows, by similar reasoning, that the ratio of capital to labour is fixed independently of fibre ratios and that the ratio of the capital-labour part to the fibre part of the production function is fixed inde-

[2] If it were felt that technological change in quality etc. is an important factor requiring a separate explanatory variable, then a time trend (logistic or otherwise) would be too broad to qualify, since it includes the effect of price changes on the trend in fibre use. A variable based on known technological facts *for each end-use* would need to be constructed; this was not possible here and hence any such variable is omitted (i.e. implicitly included in the error term).

[3] The well-known constant-elasticity-of-substitution production function developed by Arrow, Chenery, Minhas and Solow [2].

[4] This 'nested' CES production function was first propounded by Sato [12].

[5] See Blackorby *et al.* [3] for a general proof and for more discussion of the CES case, Armington [1]; the three-fibre case is spelt out in Minford [7], Appendix 1 to Chapter 1.

pendently of all these subsidiary ratios. In each case, the higher-level ratio is solely dependent on the ratio of the corresponding price indices.

The final logic of this hierarchy is that, all these ratios being fixed, the output level of the firm is determined by the ratio of an index of factor prices to the price of final output. Hence factor ratios are independent of both the output level of the firm, and by implication that of the industry. We can write fibre ratios, in particular, as functions solely of fibre price ratios; and in general we can say that the marginal productivity conditions are recursive.[6]

The textile industry is distinguished into seventy-four sub-industries, each of which produces for a separate end-use (examples are men's suits, women's and children's sweaters, and curtains). Each sub-industry is assumed to have the characteristics described in connection with the industry as a whole. Some of the implications of this model may be controversial. In particular, it is implied:

(i) That once introduced into an end-use in significant quantities, fibres do not change in 'quality' in that end-use.
(ii) That there are no lags in the 'acceptance' of a new fibre or in the adjustment of fibre ratios.
(iii) Since there is no lag in adjustment, there is no role for expectations of future fibre prices (on the grounds that, if prices change in the future, adjustment of fibre ratios can be immediate).

However, there are good reasons for adopting these assumptions, even if they inevitably represent something of an oversimplification.

The data in the first place consist of annual observations, hence the model is concerned with average annual rates. The saying goes in the industry that 'a year is a very long time in textiles'; this is the result of having to keep pace with fashion, and it is a fact that textile firms, more than most, have to keep up with new developments.

The second point about the data is that, if consumption of a fibre is less than 50,000 lbs in an end-use, it is counted as zero. The model thus only applies to new fibres once they have passed this threshold, which at the time of introduction of the new synthetic fibres, the mid-1950s, represented just under 0·1 per cent of total fibre consumption in an average end-use.

Turning to lags in adjustment, we find that textile machinery is fairly rapidly converted to the handling of any fibre or fibre blend once the technical problems have been overcome; the costs of adjustment are low. For example, a machine for tufting carpets can be easily reset to tuft a different fibre combination; a change in fibre (for example from rayon to acrylic) will require readjustment of tensions, cams, angles of cutting blades, and so on, all of which can be completed in a few hours (or at most days, depending on the exact changes). Of course, there are fibres which cannot be handled on machinery designed for a certain end-use. But this simply means that such a fibre will not be introduced in significant quantities in that end-use so that lags in adjusting to it do not arise.

As for lags in the acceptance of new fibres, these surely belong to pre-war days when the idea of artificial fibres was new. There was

[6] See Minford [7], Appendix 2 to Chapter 1, for further discussion.

indeed a long acceptance lag in the case of rayon filament in the first three decades of this century. But by 1949, when the period examined begins, viscose filament had been in existence for fifty years, viscose staple for fifteen, acetate filament for twenty-seven, acetate staple for ten and nylon filament for eight. The textile industry had by then grown familiar with new fibres and come to expect new developments.

Furthermore, a new fibre in the post-war era has a long 'pre-launching' phase in any end-use to which it is to be introduced. When it appears in significant quantities in that end-use (as defined earlier), it has been reasonably well-known to fibre buyers, and has been tested in small quantities, for several years. There follows, in the first few years of significant usage, the period of teething when fibre technicians will solve minor headaches. But its essential 'quality' is fixed once it is used in significant quantities and its 'acceptance' in that end-use has usually occurred by then, though some scepticism will remain until the end of the teething period.

There is one final assumption to be added to complete the model: that each fibre price ratio is exogenous (that is, independent of random changes in the ratio of fibre demand in any individual end-use). This can reasonably be defended.[7] Most end-uses contribute only a small proportion of the U.S. demand for a particular fibre.

Furthermore, each of the man-made fibres is produced in the U.S. under conditions of oligopoly.[8] U.S. man-made fibre producers tend to aim for price stability, this being probably the result of the need to maintain pricing discipline (see Scherer [13]). Hence current changes in demand are unlikely to affect the prices charged; instead capacity utilization, stocks, and orderbooks are likely to be varied. Prices will be varied in lagged response to a sustained change in demand.

Wool, unlike man-made fibres, is imported by the U.S. in large quantities; just over 75 per cent of its wool requirements were imported in 1968. Changes in the U.S. domestic wool price will therefore be closely related to changes in the world price. The largest of the U.S. end-uses for wool, namely women's coats and jackets, only contributed 2·2 per cent of world wool consumption in 1968. Changes in wool demand from this end-use therefore could have had at most an insignificant effect on the world price of wool and hence also on the U.S. price.

The price of cotton in the U.S. was pegged to the user by a Government support price and export subsidy system, until 1966, when the Government replaced this with a direct production subsidy so that the domestic price is now closely related to the world price. Thus, from 1949 to 1966, the cotton price was exogenous because of Government regulation, and from 1966 onwards, individual end-uses for cotton, none of them as we have seen constituting more than 10 per cent of U.S. cotton demand, were competing in a world market for cotton six-and-a-half times as large as the U.S. market.

[7] Note however that any simultaneity tends to bias the elasticity estimate towards zero, so favouring our ultimate conclusion that fibres are generally close substitutes.

[8] The point made in this paragraph should not of course be confused with the assumption made above that fibre *users* are perfectly competitive.

The model therefore can be written in its reduced form, as a set of marginal productivity conditions with price ratios as the independent variable. We can write them, for the three-fibre case as:

$$F_1/F = k_1^{\sigma}[P_1/P_F]^{-\sigma}\, u_{1F} \tag{2}$$

$$F_2/F_3 = k_2^{\eta}[P_2/P_3]^{-\eta}\, u_{23} \tag{3}$$

were $\sigma = 1/(r+1)$, and $\eta = 1/(s+1)$, P_F is the price index of the fibre group (F_2, F_3), F is the volume index for the group, and u_{1F}, u_{23} are error terms (representing commercial misjudgements and any omitted variables).

Data

The data on U.S. fibre quantities (in pounds weight) are taken from the *Textile Organon*, a monthly magazine published by the U.S. Textile Economics Bureau. Each year the *Textile Organon* carries out a survey of fibre consumption by end-use; the survey is regarded by the U.S. textile industry as their prime source of statistics on inter-fibre competition.[9] The survey results, which are available for a continuous span of years from 1949, have been used here.

The usual problems of revisions apply in this case. For the years 1949 to 1959 the figures were collected on a rather different basis than those from 1960 to 1968 and were not revised, though admitted to contain errors, particularly in the classification of the new synthetics that emerged in the late 1950s. Within each period, however, the data are on a broadly consistent basis; and fortunately data are available for 1960 on both bases. It was assumed that in general the error in the earlier period was as a percentage equal to the percentage error in 1960. But in a few cases, where this caused early relationships to blow up implausibly, the error was assumed to be additive.

Six types of fibre are distinguished: the traditional fibres (cotton and wool), the cellulosics (filament and staple), and the synthetics (filament and staple). Historically, the cellulosics or rayon[10] (produced by either the viscose or the acetate process) emerged in the first quarter of this century, initially only in filament form, but later also as a staple. The synthetics, which consist of nylon, polyester, acrylic and polypropylene fibres, emerged in that order, nylon filament in the 1940s, polyester filament in the early 1950s, polyester, nylon and acrylic staple in the mid-1950s, and polypropylene (filament and staple) most recently of all in the mid-1960s.

This classification isolates the most important differences (from the demand side, with which we are concerned) among the man-made fibres. Cellulosics, obtained by processing woodpulp, have significantly different properties from synthetics, which are made by synthesizing petro-chemicals. For example synthetics are stronger, more resilient, can be heat-set, and, because strong, are easy to use in textile processes; but they are less moisture-absorbent (important, for example, in under-

[9] The end-use division is itself not beyond criticism, with regard to the degree of aggregation and the type of grouping. The substitution elasticities estimated need to be interpreted with this in mind.

[10] Strictly only viscose is 'rayon'—but I have loosely used the term to cover all cellulosics.

wear) suffer from pilling (fluffiness when the fabric is used) and static, and are more difficult to dye. The distinction between filament (man-made fibre produced in a continuous thread) and staple (filament cut into short lengths similar to cotton or wool staples), is also fundamental, since in filament form a man-made fibre has maximum strength, while in staple form it can compete in the end-uses which require the properties of spun fibre, its rougher texture, its bulkiness, its 'breathing' quality, and so on.

Any classification of fibres must do some violence to real distinctions that have to be ignored. For example, the distinctions have been ignored between the two rayon processes, viscose and acetate, and between the four synthetic types, nylon, polyester, acrylic and polypropylene. We have unweighted quantities for each of the six main fibre types.

For the prices of cotton, wool, rayon filament and rayon staple, the *Textile Organon* have published monthly series that are on a broadly consistent basis over the whole period; unweighted twelve-month averages of these series were taken as the average price of each fibre.

There has been a minor change in basis for the cotton price (to domestic users), which was an average of ten domestic markets up to and including 1954, and since then has been an average of fifteen (sometimes fourteen) domestic markets; this change had no perceptible effect on the monthly series, which is what one would expect from a broadening of the basis.

Of the two main rayon processes, viscose and acetate, by far the most widely used has been viscose. Hence viscose was chosen as the representative rayon price (price changes in the two series have been similar). For prices of synthetic fibres, not reported by the *Textile Organon*, the Economics Department of Courtaulds Limited have kept a record, based on a reading of the textile trade journals. From this record were extracted the prices of a typical nylon filament (70/23 normal tenacity), polyester filament (70/54), acrylic staple (Orlon, 3 denier regular), and polyester staple (1½ denier, 54); again, an unweighted monthly average of each was used as the annual average prices. The prices of nylon and polyester filament were then combined in an unweighted average to give a price for synthetic filament, those of acrylic and polyester staple combined in the same way to give a price for synthetic staple.

The price data are affected by the existence of quantity, and other, discounts given by the U.S. man-made fibre producers against the list prices which have been used here. If the discounts are a constant percentage of listed prices, the percentage can be reated as a logarithmic constant, and, knowing that this is roughly 10 per cent in a normal year, we can allow for the bias in the constant term of the regression. However, it is well-known that in periods of excess capacity it is larger than in other periods.[11] This suggested that the error term would follow the cycle in textile activity, and would be autocorrelated. We can rewrite, for example, model equation (3) as:

$$(4) \qquad F_2/F_3 = k_3^{\eta}[cv\, P_2/P_3]^{-\eta}\, u_{23} = k_3^{\eta}[c\, P_2/P_3]^{-\eta}\, v^{-\eta}\, u_{23},$$

where c is the constant part of the fractional discount (the normal discount), v is the variable part.

[11] See, for example, Markham [6], especially pp. 79-80.

Estimation Techniques

The parameters of the fibre section of the production function are estimated, in the method made familiar by Arrow, Chenery, Minhas, Solow [2] and subsequently others, from the marginal productivity equations in the loglinear form:

$$\log F_i/F_j = \sigma \log k - \sigma \log (P_i/P_j) + \log u_{ij}. \quad (5)$$

The first stage was to estimate the elasticity of substitution between individual fibres. Those fibres which shared a high and significant elasticity were then classed as a group. There might be several potential sets of groups.

The next stage was to estimate the elasticities of substitution between the groups in each potential set. This was done by using indices as described earlier.[12] Formally:

$$F = [k_2F_2^{-s} + F_3^{-s}]^{-1/s} \text{ and } (7)\ P_f = P_3[F_3/F]^{s+1} \quad (6)$$

However, we do not know the true values of k_2 and s, so we substitute the estimated values into the expression for F and P_f.

$$\hat{P}_f = P_3(F_3/\hat{F})^{\hat{s}+1} \quad (8)$$

is independent of u_{1F}, by virtue of the recursiveness of the system and the independence of u_{1F} and u_{23}; in other words $F_3/\hat{F}$ is exogenous in this equation, because it is a function solely of P_2/P_3 and u_{23}, both of which are independent of u_{1F} by assumption.

To reduce the number of potential sets to manageable size, all fibres that at no point in the period absorbed a significant proportion of consumption in a particular end-use, were excluded from the analysis of that end-use; clearly, the substitution represented by their variation is of no importance either to their own consumption or to the consumption of other fibres.

Where a choice had to be made between groupings, three criteria were borne in mind:

(i) A condition imposed by the model is that the elasticity of substitution of any group of fibres be not significantly less than the elasticity between that group and other fibres. This condition follows from our definition of a 'group', defined as a number of fibres which substitute at least as, or more, closely with each other than with fibres outside the group. For example, if coffee is found to substitute more closely with tea than different types of tea do among themselves, then it is wrong to consider 'coffee' and 'tea' as groups; we might look instead at the substitution between coffee, grade A, and tea, grade A. Or we might find that Indian tea is a close substitute for coffee, with China tea as a general substitute for both.

(ii) The comprehensiveness of the grouping was considered. For example, if there were four fibres involved, then a grouping which succeeded in relating all four would in general be preferred to one that only related three.

[12] The sensitivity of the results to different methods of indexing needs further research. For some preliminary discussion, seen Minford [7], Appendix 4 to Chapter 1.

(iii) The relative statistical significance of the elasticities as measured (albeit imperfectly, as discussed below) by their t-statistics was taken into account.

In most cases, the most satisfactory grouping was reasonably clear. However, in some end-uses, particularly those with five or six competing fibres, an element of subjective judgement inevitably entered. The regression results, for the groupings which emerged in this manner, are presented for all but the small end-uses in Table 1.

The statistical significance of the results presented in Table 1 requires careful interpretation for two reasons. First, the data were used not only to estimate the elasticity of substitution between fibre pairs but also to select the correct groupings of the fibres. The process of selection involved to some extent passing over fibre pairs with lower or wrongly-signed or 'insignificant' elasticities. The benefit of this is that more information is extracted from the data; the loss, as discussed by Theil [14; Ch. 12, pp. 603-6], is that the standard significance tests no longer strictly apply to the 'final' group's elasticities, because the probability of obtaining 'significant' results is raised by the selection process. A similar loss occurs in many econometric studies when the researcher follows the 'regression strategy' of improving his equations' specification in response to trial regressions. The usual convention (a not entirely satisfactory one—but followed here) is to report only final results and not to attempt to quantify the loss of significance.[13]

The likelihood of autocorrelated residuals was noted earlier; in many cases there was in fact evidence of autocorrelation. Since no lagged endogenous variables are used in the regressions, parameter estimates will be unbiased in spite of autocorrelation. Its effect will, however, be to remove their minimum variance property and to lead to underestimates of their standard errors.

The hypothesis was suggested, in discussion of the data, that the residuals were correlated with the cycle in textile activity. The residuals of the successful equations were examined but only in a very few cases[14] was the null hypothesis rejected with the strictly limited data available on the textile cycle; better data may increase the number. But a general explanation of the serial correlation must be the subject of further research, and could be pursued in conjunction with the investigation of non-price factors generally.

The attempt was also made to remove the serial correlation by statistical means. The Cochrane-Orcutt first-order transformation was used but it rapidly became apparent that the relationship between quantity and price ratios would disappear under this transformation. Given the high value of ρ, the first-order serial coefficient, the transformation is nearly equivalent to first-differencing; disappearance of the relationship under first-differencing could indicate the existence of a lag, probably variable since some experimentation with fixed lags proved unsuccessful. Our model assumes no lag, but this would not be a serious

[13] Theil [14] suggests that in these circumstances one should 'apply . . . significance limits liberally', after noting that the true significance limits cannot, in the present state of the arts, be determined precisely, since they depend on the true (and unknown) values of the coefficients and error variance.

[14] See Minford [7], Appendix 3 to Chapter 1 for details.

TABLE 1—*Regression Results*
(See end of Table for Notes, on abbreviations, etc.)

End-use (*Textile Organon* No.)	Regression pair	s (t)	$\bar{R}^2$	d	T	Regression pair	s (t)	$\bar{R}^2$	d	T	Regression pair	s (t)	$\bar{R}^2$	d	T
A—Men's & Boys' wear															
1 Reg., mid. & lightweight suits	Ss/Wo	2·26 (2·38)	0·22	0·60	51-68	(Ss-Wo) /Rs	1·2 (2·34)	0·21	0·72	51-68	(Ss-Wo) -Rs/Co	0			51-68
2 Tailored Civilian uniforms	Rs/Ss	4·85 (4·47)†	0·56	0·91	53-68	(Rs-Ss) /Wo	5·6 (4·26)†	0·53	1·06	53-68					
4 Separate slacks	Ss/Co	2·81 (3·46)*	0·37	0·74	49-68	(Ss-Co) /Rs	2·10 (1·95)	0·13	0·09	49-68	(Ss-Co) -Rs/Wo	2·28 (14·33)†	0·91	1.82	49-68
6 Outdoor Jackets & Athletic uniforms	Ss/Co	2·75 (5·95)†	0·64	0·78	49-68	(Ss-Co) /Wo	1·37 (1·92)	0·12	0·19	49-68	(Ss-Co) -Wo/ (Ry-Rs)	0·40 (2·82)*	0·27	0·88	49-68
	Ry/Rs	1·22 (2·02)	0·14	0·58	49-68	(Ss-Co) -Wo- (Ry-Rs) /Sy	0·92 (2·70)*	0·25	0·51	49-68					
7 Sweaters	Ss/Co	6·18 (7·14)†	0·72	0·83	49-68	(Ss-Co) /Wo	1·91 (1·81)	0·11	0·30	49-68	(Ss-Co) -Wo/Sy	0			56-68
10 Utility clothing	Ss/Co	6·96 (6·76)†	0·70	0·67	49-68										
11 Work & uniform shirts	Rs/Ss	2·87 (3·90)†	0·56	1·39	57-68	(Rs-Ss) /Wo	1·38 (1·85)	0·18	0·97	57-68	(Rs-Ss) -Wo/Co	1·53 (6·90)*	0·81	1·00	57-68
12 Business & dress shirts	Sy/Ss	6·13 (6·64)†	0·69	0·68	49-68	(Sy-Ss) /Co	5·59 (2·75)*	0·26	0·58	49-68					
13 Sports shirts woven	Rs/Ss	4·03 (6·85)†	0·71	0·75	49-68	(Rs-Ss) /(Ry-Co)	0			49-68	Ry/Co	3·93 (5·48)†	0·60	0·31	49-68
	(Rs-Ss) -(Ry-Co) /Wo	0			49-68										

(*Continued on following pages*)

End-use	Regression pair	s (t)	$\bar{R}^2$	d	T	Regression pair	s (t)	$\bar{R}^2$	d	T	Regression pair	s (t)	$\bar{R}^2$	d	T
14 Sports shirts knit	Ry/Rs	10·01 (4·01)	0·65	1·63	60-68	(Ry-Rs) /(Ss-Co)	0·79 (2·74)	0·45	1·97	60-68	Ss/Co	8·36 (5·47)†	0·66	0·93	53-68
	(Ry-Rs) -(Ss-Co) /Sy	0			60-68										
16 Underwear knit	Ss/Co	1·50 (3·22)*	0·36	1·14	51-68	(Ss-Co) /Ry	0			51-68					
17 Nightwear—woven & knit	Ry/Sy	4·52 (5·67)†	0·65	0·90	51-68	(Ry-Sy)/ (Ss-Co)	1·85 (2·23)	0·33	1·13	60-68	Ss/Co	5·55 (1·62)	0·17	0·53	60-68
18 Hosiery—all types	Ry/Rs	5·64 (6·69)†	0·70	1·23	49-68	Rs/Ss	4·97 (6·16)†	0·66	0·72	49-68	Ry/Ss	5·63 (8·72)†	0·80	0·50	49-68
	(Ry-Rs-Ss)/Wo	2·28 (4·13)*	0·46	0·88	49-68	(Ry-Rs-Ss) -Wo/Co	1·37 (3·93)*	0·43	0·60	49-68	(Ry-Rs-Ss) -Wo-Co/Sy	0			49-68
B—Women's, Girls', Children's and Infants' Wear															
19 Suits & Skirts	Ry/Sy	7·02 (6·49)†	0·68	0·84	49-68	(Ry-Sy) /Ss	2·57 (10·55)†	0·85	0·93	49-68	(Ry-Sy) -Ss/Rs	2·19 (2·02)	0·14	0·20	49-68
	(Ry-Sy) -Ss-Rs/ Co	1·37 (2·15)	0·16	0·28	49-68	(Ry-Sy) -Ss-Rs- Co/Wo	0·47 (2·10)	0·15	0·39	49-68					
20 Slacks	Rs/Wo	3·68 (2·04)	0·28	0·45	60-68	(Rs-Wo) /Ss	3·18 (5·33)	0·77	1·20	60-68	(Rs-Wo) -Ss/Sy	4·29 (1·74)	0·20	0·97	60-68
	(Rs-Wo)- Ss-Sy/Ry	0			60-68	(Rs-Wo)- Ss-Sy-Ry /Co	0			60-68					

End-use	Regression pair	s (t)	$\bar{R}^2$	d	T	Regression pair	s (t)	$\bar{R}^2$	d	T	Regression pair	s (t)	$\bar{R}^2$	d	T
21 Dresses	Ry/Sy	4·56 (7·55)†	0·75	0·67	49-68	(Ry-Sy)/(Ss-Co)	1·07 (3·76)*	0·41	0·27	49-68	Ss/Co	6·91 (8·27)†	0·78	0·99	49-68
	(Ry-Sy)-Ss-Co/(Rs-Wo)	0·61 (3·77)*	0·41	0·71	49-68	Rs/Wo	1·47 (2·56)*	0·23	1·14	49-68					
22 Coats & Jackets	Ss/Co	4·08 (4·56)†	0·78	0·99	51-68	(Ss-Co)/Rs	4·46 (5·83)†	0·66	0·37	51-68	(Ss-Co)-Rs/Wo	3·03 (4·27)†	0·50	1·09	51-68
	(Ss-Co)-Rs-Wo/Ry	1·21 (4·30)*	0·51	0·51	51-68	(Ss-Co)-Rs-Wo-Ry/Sy	0			51-68					
24 Playsuits, Sunsuits & Shorts	Ss/Co	4·15 (6·66)†	0·73	1·30	52-68	(Ss-Co)/Rs	0			52-68					
25 Sweaters	Ss/Wo	2·23 (2·26)	0·18	0·26	49-68	(Ss-Wo)/Sy	0			55-68					
27 Loungewear	Rs/Wo	2·08 (2·54)*	0·22	0·60	49-68	(Rs-Wo)/(Ss-Co)	0			60-68	Ss/Co	1·29 (1·46)	0·12	0·54	60-68
	(Rs-Wo)-(Ss-Co)/(Ry-Sy)	0			60-68						Ry-Sy	0·62 (1·41)	0·05	0·51	49-68
29 Work Clothing	Ss/Co	4·38 (2·43)	0·29	0·45	56-68										
30 Blouses	Ry/Rs	2·72 (7·75)†	0·76	0·74	49-68	(Ry-Rs)/Sy	3·15 (3·01)*	0·30	0·23	49-68	(Ry-Rs)-Sy/(Ss-Co)	1·14 (2·77)	0·28	0·27	51-68
	Ss/Co	5·66 (5·03)†	0·59	0·95	51-68										

End-use	Regression pair	s (t)	$\bar{R}^2$	d	T	Regression pair	s (t)	$\bar{R}^2$	d	T	Regression pair	s (t)	$\bar{R}^2$	d	T
33 Underwear—knit	Ry/Sy	2·38 (4·84)*	0·54	0·45	49-68	(Ry-Sy)/Co	0			49-68					
35 Nightwear—knit	Ry/Sy	4·32 (6·35)†	0·67	0·46	49-68	(Ry-Sy)/Ss	4·76 (1·77)	0·35	1·10	64-68	(Ry-Sy)-Ss/Co	0			64-68
36 Full-length hosiery	Ry/Sy	3·85 (6·26)†	0·67	0·42	49-68	(Ry-Sy)/Co	0			49-68					
C—Home furnishings															
40 Bedspreads & quilts	Ry/Rs	2·55 (6·26)†	0·67	0·92	49-68	(Ry-Rs)/(Ss-Co)	1·39 (2·37)	0·54	1·61	64-68	Ss/Co	5·46 (2·15)	0·47	1·13	64-68
	(Ry-Rs)-(Ss-Co)/Sy	0·92 (2·22)	0·48	1·14	64-68										
41 Blankets & blanketing	Rs/Ss	3·64 (7·31)†	0·77	0·96	52-68	(Rs-Ss)/Co	4·31 (1·76)	0·12	0·34	52-68	(Rs-Ss)-Co/Wo	1·39 (1·73)	0·11	0·56	52-68
42 Sheets and other bedding	Ss/Co	9·21 (1·98)	0·42	0·97	64-68	Ss-Co/Rs	0			64-68					
43 Towels & towelling	Rs/Co	0			55-68										
45 (i) Carpets, Tufted, face yarns	Rs/Ss	4·71 (5·41)†	0·67	0·43	54-68	(Rs-Ss)/Wo	3·39 (5·49)†	0·68	0·07	54-68	(Rs-Ss)-Wo/Sy	0			57-68
	(Rs-Ss)-Wo-Sy/Co	0			57-68										
45 (ii) Carpets, woven, knit & needle punch, face yarns	Rs/Ss	9·15 (5·08)†	0·63	0·44	53-68	(Rs-Ss)/Wo	5·07 (4·53)†	0·56	0·82	53-68					
46 Curtains	Ry-Co	1·32 (3·76)*	0·41	0·66	49-68	(Ry-Co)/Sy	1·73 (2·19)	0·17	0·26	49-68					

End-use	Regression pair	s (t)	$\bar{R}^2$	d	T	Regression pair	s (t)	$\bar{R}^2$	d	T	Regression pair	s (t)	$\bar{R}^2$	d	T
47 Drapery	Ry/Sy	6·90 (4·73)†	0·53	0·31	49-68	(Ry-Sy)/(Ss-Co)	0			49-68	Ss/Co	4·13 (6·65)†	0·69	1·13	49-68
	(Ry-Sy)-(Ss-Co)/Rs	0			49-68										
D—Other consumer-type products															
49 Apparel linings	Ry/Rs	2·24 (3·38)*	0·35	0·53	49-68	(Ry-Rs)/(Ss-Co)	0·38 (4·18)*	0·51	0·82	52-68	Ss-Co	6·36 (8·64)†	0·82	1·46	52-68
	(Ry-Rs)-(Ss-Co)/Sy	1·32 (1·78)	0·13	0·44	53-68										
50 Retail piece goods	Ss/Co	4·81 (4·56)†	0·55	0·65	52-68	(Ss-Co)/Wo	0·98 (3·35)*	0·39	0·66	52-68	(Ss-Co)-Wo/(Ry-Sy)	0			52-68
	Ry/Sy	5·30 (6·91)†	0·74	0·57	52-68	(Ss-Co)-Wo-(Ry-Sy)/Rs	0			52-68					
51 Narrow fabrics	Ry/Sy	5·65 (7·67)†	0·78	0·60	49-68	(Ry-Sy)/Co	0			49-68					
53 Shoes & Slippers	Ry/Sy	1·34 (1·69)	0·10	0·67	52-68	(Ry-Sy)/Co	0			52-68					
57 Miscellaneous Consumer type products	Rs/Ss	3·17 (10·70)	0·93	1·13	60-68	(Rs-Ss)/Ry	0			60-68					
E—Industrial uses															
58 Transport Upholstery	Ry/Rs	2·28 (3·13)*	0·37	1·20	53-68	(Ry-Rs)/Co	2·19 (3·38)*	0·41	0·61	53-68	(Ry-Rs)-Co/(Ss-Wo)-Sy	0			53-65
	Ss/Wo	5·40 (2·77)*	0·29	1·08	49-65	(Ss-Wo)/Sy	0			49-65					
60 Tyres	Ry/Sy	9·51 (8·37)†	0·78	0·49	49-68	(Ry-Sy)/Co	0			49-68					

End-use	Regression pair	s (t)	$\bar{R}^2$	d	T	Regression pair	s (t)	$\bar{R}^2$	d	T	Regression pair	s (t)	$\bar{R}^2$	d	T
62 Belting	Ry/Sy	6·27 (5·28)†	0·63	0·49	52-68	(Ry-Sy)/ Co	0			52-68					
67 Sewing Thread	Ry/Rs	22·32 (6·35)	0·91	2·03	64-68	(Ry-Rs)/ Co	0			64-68	(Ry-Rs)- Co/Sy	0			64-68
68 Rope, Cordage, fish line, etc.	Ry/Sy	5·29 (6·46)†	0·68	0·42	49-68	(Ry-Sy)/ Rs	5·56 (3·14)	0·53	1·16	60-68	(Ry-Sy)- Rs	0			60-68
69 Bags & bagging	Sy/Co	17·6 (6·91)	0·93	3·32	65-68										
71 Paper & tape reinforcing	Rs/Ss	1·76 (4·53)	0·69	3·07	61-67	(Rs-Ss)/ Ry	0·99 (2·34)	0·43	2·14	61-67	(Rs-Ss)- Ry/Sy	1·47 (2·08)	0·36	1·88	61-67
	(Rs-Ss)- Ry-Sy/Co	0			61-67										

Other end-uses:

For the following end-uses s = 0 for all fibre pairs (fibres involved are bracketed): 45 (iii) Primary backing (carpets) (Sy, Ss, Co); 56 Medical, Surgical and Sanitary (Rs, Co); 70 Tarpaulins, Tents, Parachutes, etc. (Sy, Co); 72 Reinforced Plastics (Sy, Co); 74 Miscellaneous industrial (Rs, Sy, Co). Results for other end-uses are omitted because each end-use represented less than 0·5% of total fibre usage in 1968; for these, see Minford [7].

Notes:

(1) Opposite each end-use is shown the successful overall grouping, and for each regression pair:
 (a) the estimated elasticity of substitution (s), together with its t-statistic.
 (b) the R-squared (corrected for lost degrees of freedom), $\bar{R}^2$.
 (c) the Durbin- Watson statistic, d.
 (d) the years over which the equation was estimated, T.
The equation estimated is the relevant marginal productivity condition in logarithmic form (see text); natural logarithms were used.

(2) The following abbreviations have been used:
Ry = Rayon filament (or 'yarn' as filament is often called). Sy = Synthetic filament (or yarn). Co = cotton.
Rs = Rayon staple (filament cut into staple lengths). Ss = Synthetic staple (filament cut into staple lengths). Wo = wool.

(3) Where s was wrongly signed or quite insignificant, the relevant estimate of σ, the elasticity of substitution, is zero since $\sigma \geqslant 0$; s = 0 is accordingly shown in the table.

(4) Fibres not shown in the grouping were negligible in quantity.

† significantly > 1 } (5% level; one-sided test) with corrected standard error—see text.
* significantly > 0 }

mis-specification for estimation in levels. Nevertheless, it effectively prevents the statistical removal of serial correlation.

It is however open to us to adjust the coefficient standard errors for the inefficiency caused by its presence.[15] The correction factor depends on ρ (a point estimate of which is provided by the Durbin-Watson statistic) and the degree of autocorrelation in the independent variable (i.e. the fibre price ratios). For example, given $\rho = 0{\cdot}5$, the factor by which the *t*-statistics should be divided ranges from 1·1 to 1·6 depending on which fibre combination is involved; for a high ρ of 0·9, it ranges from 0·9 to 2·1. It was not possible to recalculate all the standard errors in this way, but these factors were used as a basis for reappraising the significance of the results in an approximate fashion. Elasticity estimates which retain (5 per cent level) significance are asterisked in the table; those which are significantly greater than unity are shown with a dagger. After adjustment, out of the 215 estimated elasticities, 86 were significantly greater than zero, and 59 of these were significantly greater than unity.

There is significant evidence of positive and often high substitution elasticities at the disaggregated end-use level. However, apart from significance tests, we are interested in the information provided by these results, which consist of a considerable number of unbiased estimates of elasticities of substitution between fibres.

The 'story' behind these results is sketched for each end-use in Minford [7, pp. 17-40], but here we note some salient features. As illustrated by Figures 1 and 2, overall market shares of synthetic yarn and staple grew during the period at the expense of cotton, wool and rayon yarn in that order, with rayon staple broadly holding its share; there was a large drop in synthetic staple prices, a smaller slide in the prices of wool, rayon staple and synthetic yarn, with cotton prices falling less than these until the end of the period and wool briefly soaring during the Korean War, while rayon yarn prices grew steadily throughout. The role of price in the market growth of synthetic staple is evidenced by high elasticities with the dominant fibres in most end-uses; for example, in men's suits with wool, in sheets with cotton, in tufted carpets with rayon staple, in woven carpets again with wool. Rayon staple, while losing share to synthetic staple, gained mainly from cotton significantly on price grounds. Price competitiveness is generally high between synthetic yarn and rayon yarn, which the former displaced in a variety of end-uses requiring fibre strength (e.g. tyre cord, women's stockings). Yet the displacement of cotton and wool by synthetic yarn in several knitwear end-uses appeared not to be due to price but to the progress of machine-knitting technology with which it is complementary; and cotton gave way to man-made filaments as a group in many consumer-type and industrial uses primarily on non-price grounds. In further research, these technological changes could usefully be captured in additional variables; it may be that allowance for them would reveal more price competitiveness than is at present apparent. Nevertheless,

[15] This is discussed by Johnston [5], pp. 246-9. An appendix showing the derivation of these adjustments is available on request from the author.

Figure 1.

MARKET SHARES OF FIBRES IN TOTAL US CONSUMPTION 1949-68

(per cent)

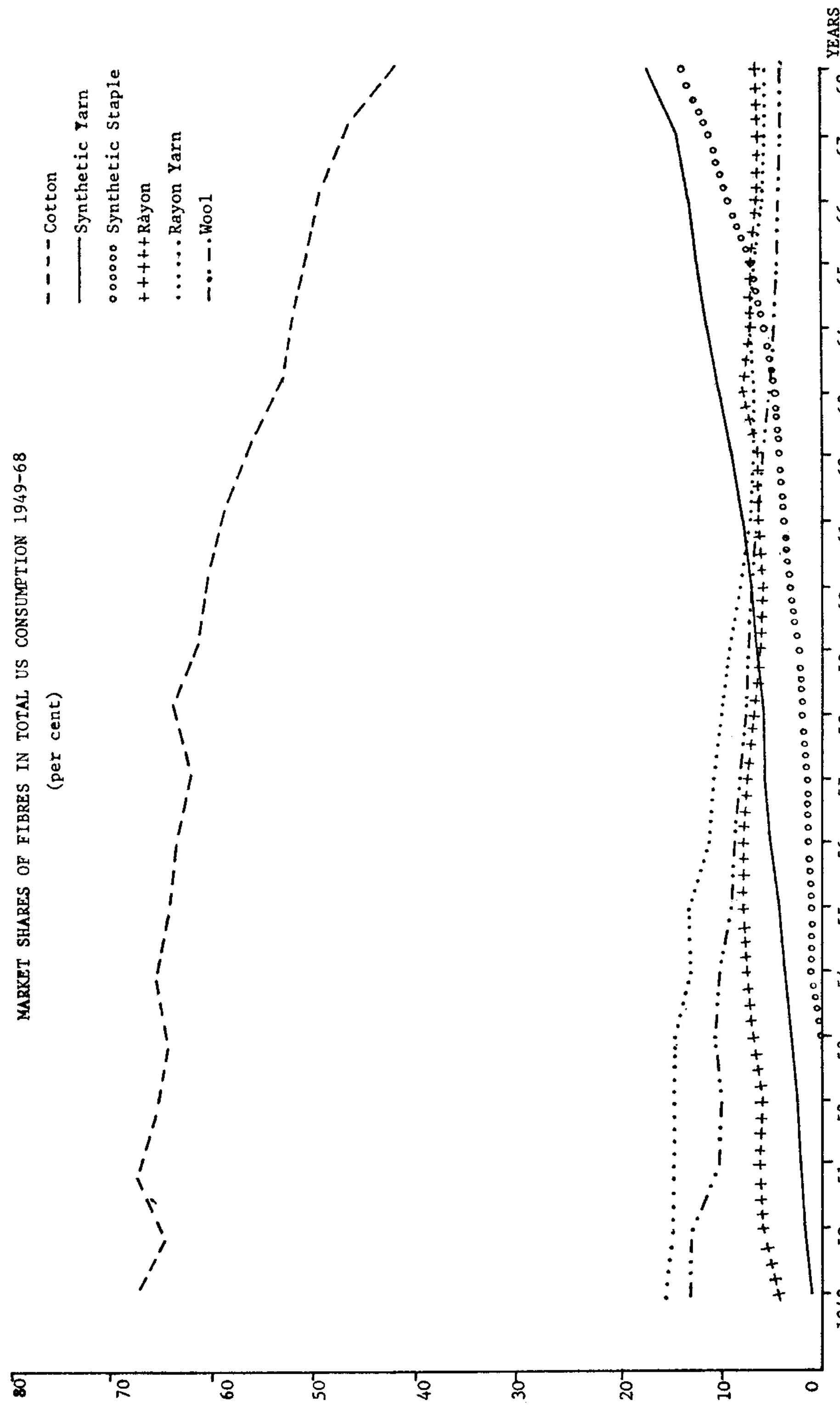
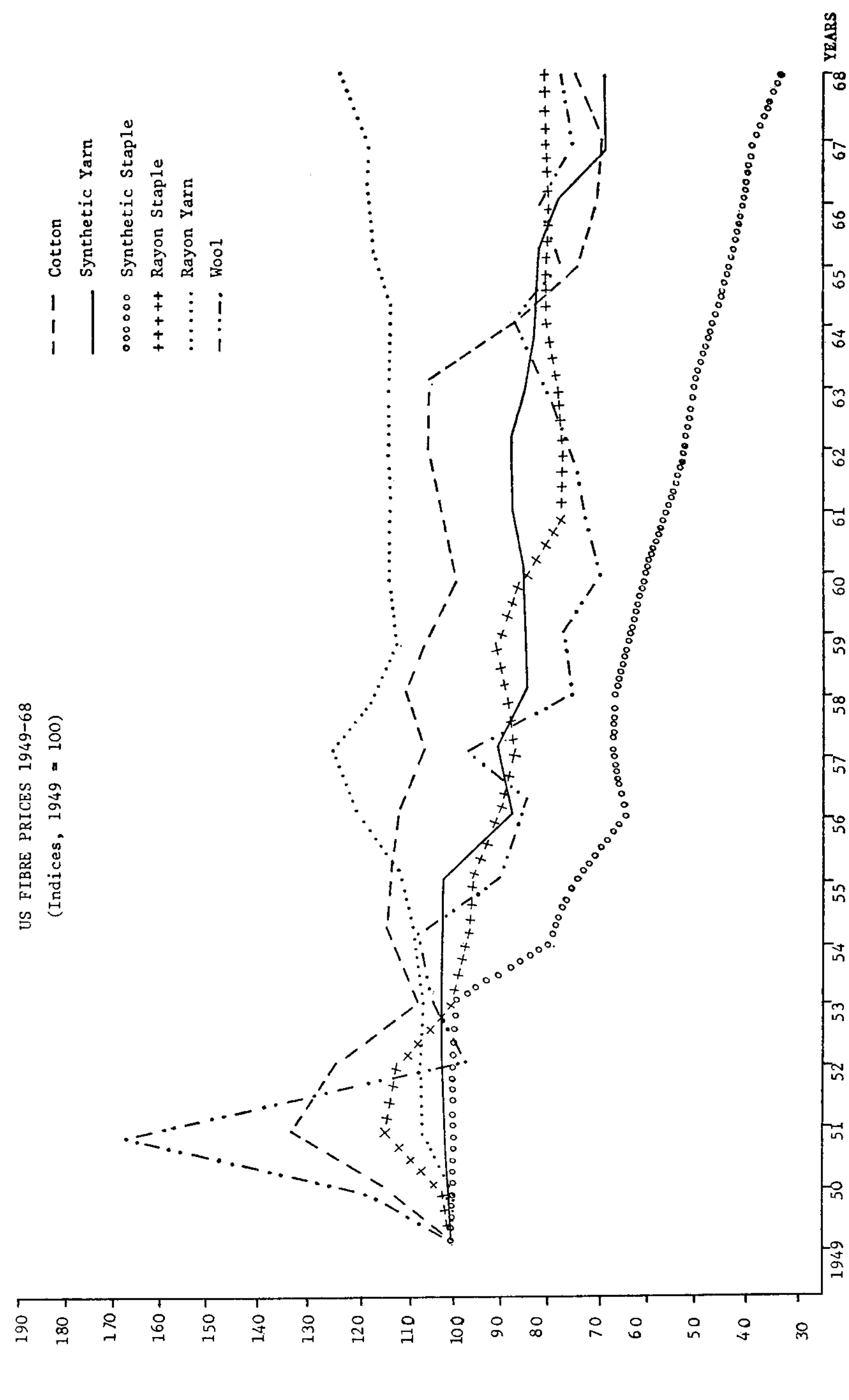


Figure 2



US FIBRE PRICES 1949-68
(Indices, 1949 = 100)

the extent of substitutability uncovered here carries conviction, at least as a minimum.

Economic theory suggests that fibres known to be 'competitive' with one another (in the jargon of the trade) should display substitution elasticities higher than unity, how much higher depending on the degree of 'competitiveness'. The range here mostly lies between 1 and 5 (see Table 2), which is consistent with the prediction of the theory. The mean elasticity for the whole sample is 2·5. For the sample of positive elasticities (i.e. for those fibre pairs which are apparently substitutes) it is 3·6. Thus these estimates, even when they are not significant, may be considered as reasonably plausible for the most part.

TABLE 2

Size Distribution of Elasticities Estimated

Range of Elasticity	Percentage of elasticities falling within range
$s = 0$	30·2
$0 < s \leqslant 1$	7·0
$1 < s \leqslant 2$	13·9
$2 < s \leqslant 3$	13·0
$3 < s \leqslant 4$	9·8
$4 < s \leqslant 5$	11·2
$5 < s \leqslant 6$	6·5
$6 < s$	8·4

Source: Table 1. The total number of elasticities, for which results are given in Table 1, is 215.

Testing the Null Hypothesis for Textile Fibres Generally

We would like to draw some conclusions about fibre substitution in general from the individual results discussed above. Since these results represent unbiased elasticity estimates we may test the null hypothesis for fibre substitution generally (i.e. for the mean of the fibre elasticity 'population').

The mean of these individual s_i, $\bar{s_i}$, is 2·50 and the standard deviation 2·88. From the central limit theorem s_i is distributed around σ approximately normally (since N is very large), with standard error, 0·196. Hence we may set 5 per cent confidence limits for σ as 2·12 and 2·28, and reject the null hypothesis that $\sigma = 0$ with virtually total confidence; the null hypothesis that $\sigma \leqslant 1{\cdot}70$ may be rejected with equal confidence.

It may be objected that, as a result of the procedure adopted (especially in the search for the correct grouping) elasticity estimates most favourable to rejection of the null hypothesis have been selected, and that a proper test would include all estimated elasticities (whatever their sign) either for all possible groupings or for a grouping selected on grounds independent of these data. There is an element of truth in such an objection, though its seriousness may reasonably be doubted in view of the overwhelming rejection of the null hypothesis noted above.

Unfortunately, we are unable to carry out the test suggested for the disaggregated data; 'all possible groupings' is an impracticably large set, and we do not have independent grounds available to us for selecting a single grouping (indeed, if we had one, we would have used it to start with).

However, a further test can be devised based on more aggregated results. We assume that at a suitable level of aggregation, 'nesting' disappears from the fibre production function and there is a single 'average' elasticity of substitution between all or at least the main fibres; this implies an unambiguous one level grouping and within the aggregated end-use allows us to regress each individual fibre ratio against the corresponding fibre price ratio. Table 3 presents results on this basis for five groupings aggregated over the 74 sub-categories previously considered.

We pass over the statistical significance of these aggregate elasticities (indicated in Table 3 as in Table 1) and perform two tests for the population mean, first including all fibres, second excluding from each end-use those fibres with less than 10 per cent of the end-use consumption both at the beginning and end of the period (see Table 4).

For all fibres the mean s_i was 1·37. The standard deviation of the s_i was 2·86, and with $N = 75$, the standard deviation of the mean, $\bar{s}_i$, was therefore 0·33. Hence we may reject the null hypothesis that $\sigma = 0$ with total confidence, while the 95 per cent confidence interval for σ is 0·71 to 2·03.

Excluding minor fibres, the mean $\bar{s}_i$ is 1·78, the standard deviation of the s_i is 3·06 and of the mean, $\bar{s}_i$, (with $N = 37$) consequently 0·5. Again, $\sigma = 0$ can be rejected with total confidence while the 95 per cent confidence interval for σ is 0·78 to 2·78.

Whereas the test on the disaggregated results may have favoured rejection of the null hypothesis, it is clear that both of these latter tests on aggregated data are biased against rejection. By aggregating, we lose much of the information that enabled us to pinpoint σ rather precisely.

Of the two tests, the first may be the worse; the inclusion of minor fibres, whose substitutability within the end-use is likely to be small, may give s_i a downward bias, since these minor fibres should probably be 'nested' separately with a lower than 'average' elasticity.

Therefore the truth appears to be somewhere between the results of the disaggregated and the aggregated tests (especially that excluding minor fibres). We might summarize, on this basis, by saying that: σ, the average elasticity of substitution between fibres, is almost certainly positive; is very probably (80-90 per cent confidence) greater than unity (elastic); is most likely to lie between 1½ and 2½; is very probably (95 per cent confidence) less than 2¾; but is almost certainly less than 3¾.

Conclusions

Three questions must be the subject of further research[16]; these concern the recursiveness of the model, the serial correlation of the residuals, and the indexing procedure. There is also the question of how the fibre substitution not explained by fibre prices can be explained,

[16] Material discussing these issues in a preliminary way, as well as the data, is available on request from the author; or see Minford [7], Appendices 2-4 and Data Annex to Chapter 1.

TABLE 3—*Regression Results for 5 Aggregated End-uses, 1949-68*

Fibre Pair	I. Male Clothing (end-uses 1–18) −s (t)	$\bar{R}^2$	d	II. Female Clothing (end-uses 19–39) −s (t)	$\bar{R}^2$	d	III. Home Furnishings (end-uses 40–48) −s (t)	$\bar{R}^2$	d	IV. Other Consumer Products (end-uses 49–57) −s (t)	$\bar{R}^2$	d	V. Industrial Uses (end-uses 58–74) −s (t)	$\bar{R}^2$	d
Ry/Rs	−1.95 (10.86)†	0.86	1.10	−1.63 (5.87)†	0.64	1.07	−2.36 (9.83)†	0.83	1.19	−4.79 (5.53)†	0.61	0.43	−3.30 (6.20)†	0.66	0.57
Ry/Sy	−4.73 (6.32)†	0.67	0.48	−2.97 (4.77)†	0.53	1.47	−5.99 (7.62)†	0.75	0.43	−1.89 (6.66)†	0.70	0.60	−5.89 (9.22)†	0.82	0.59
Ry/Ss	4.31 (15.00)	0.92	0.80	−2.95 (5.95)†	0.65	1.87	−5.42 (10.36)†	0.85	0.39	−3.51 (9.11)†	0.81	0.84	−1.93 (8.65)†	0.80	0.56
Ry/Co	−1.44 (3.48)*	0.37	0.18	−0.24 (0.50)	−0.04	1.06	0.58 (4.37)	0.49	0.97	0.78 (5.48)	0.60	0.57	−0.34 (1.33)	0.04	0.71
Ry/Wo	−1.27 (8.55)*	0.79	1.20	−0.67 (2.71)*	0.25	1.36	0.98 (3.01)	0.30	0.70	0.69 (3.35)	0.35	0.69	1.74 (5.79)	0.63	0.96
Rs/Sy	−1.39 (0.83)	−0.02	0.12	0.31 (0.28)	−0.05	1.05	0.31 (0.14)	−0.05	0.08	1.48 (0.78)	−0.02	0.11	0.10 (0.07)	−0.06	0.16
Rs/Ss	−5.24 (8.55)†	0.79	0.73	3.21 (4.01)	0.44	1.77	−6.62 (6.65)†	0.69	0.42	−4.16 (5.91)†	0.64	0.87	−0.68 (3.35)*	0.35	1.38
Rs/Co	0.87 (2.70)	0.25	0.74	1.34 (2.13)	0.16	1.09	−0.23 (0.22)	−0.05	0.11	0.09 (0.10)	−0.05	0.08	0.02 (0.02)	−0.06	0.12
Rs/Wo	−0.51 (1.50)	0.06	0.34	−0.49 (0.97)	−0.003	0.65	1.46 (1.09)	0.009	0.30	1.63 (1.74)	0.10	0.45	2.73 (1.68)	0.09	0.39
Sy/Ss	−3.15 (9.55)†	0.83	1.25	−2.54 (6.02)†	0.65	2.16	−3.92 (4.78)†	0.54	0.39	−1.86 (4.57)†	0.51	2.42	1.60 (4.59)	0.51	0.66
Sy/Co	1.11 (0.81)	−0.02	0.19	1.54 (1.42)	0.05	0.30	3.14 (1.06)	0.006	0.09	1.59 (0.61)	−0.03	0.07	1.49 (0.60)	−0.03	0.08
Sy/Wo	1.13 (1.12)	0.01	0.29	0.07 (0.09)	−0.05	0.36	2.47 (1.13)	0.01	0.17	3.28 (1.98)	0.13	0.32	3.85 (1.89)	0.12	0.29
Ss/Co	−5.35 (8.20)†	0.78	1.01	−4.10 (5.41)†	0.60	1.42	−9.81 (8.82)†	0.80	1.12	−6.36 (7.59)†	0.75	1.36	−2.84 (6.72)†	0.70	1.12
Ss/Wo	−4.55 (4.58)†	0.51	0.71	−3.60 (4.21)†	0.47	1.54	−7.00 (3.37)†	0.35	0.47	−4.32 (3.07)*	0.31	0.56	−3.42 (4.07)†	0.45	0.69
Co/Wo	0.03 (0.13)	−0.05	0.41	0.22 (1.41)	0.05	1.45	−0.31 (0.84)	−0.02	0.36	0.27 (1.31)	0.04	0.47	0.88 (1.55)	0.07	0.26

Notes: As in Table 1. The constant term (included as before) is not reported for these regressions, for the sake of brevity. All regressions were estimated for the full period, 1949–68. In this Table, *unlike* Table 1, a positive sign on *s* implies the elasticity is wrongly signed.

TABLE 4—*Consumption of Fibres by Main End-Uses in 1949 and 1968 (million lbs.)*

		Ry	Rs	Sy	Ss	Co	Wo	Total
I. Male	1949	39·0	64·7	4·3	2·9	835·3	168·1	1114·3
clothing	1968	17·8	86·2	77·7	493·5	1068·7	170·3	1914·2
II. Female	1949	204·5	75·1	39·6	4·5	321·2	152·5	797·5
clothing	1968	258·6	210·0	340·1	358·6	561·0	175·2	1903·5
III. Home	1949	40·8	33·4	4·5	0·1	758·5	190·3	1027·6
furnishings	1968	99·0	399·3	485·8	585·7	1260·6	97·7	2928·1
IV. Other con-	1949	125·1	18·5	1·1	0·9	399·6	42·6	587·7
sumer prods.	1968	220·7	135·4	71·4	145·0	506·5	26·8	1105·8
V. Industrial	1949	262·0	7·2	28·7	2·1	893·3	47·5	1240·8
uses	1968	210·8	53·8	906·8	39·3	592·5	8·6	1811·8

and whether fibre prices play a subsidiary part in such an explanation; this question is closely linked with the serial correlation problem.

Nevertheless, it was shown that textile fibres are on the average definitely price sensitive with an elasticity of substitution significantly greater than unity and most probably in the region of 2. At the disaggregated level, it was found that about 40 per cent of the individual elasticities examined were significantly positive and, of these, two-thirds were significantly greater than unity; the remaining non-significant (but unbiased) estimates were generally of a plausible magnitude. The main general conclusion of this study is therefore that in the area of textile fibres, the price mechanism works in the manner predicted by marginal productivity analysis.

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