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STRUCTURAL CHANGE OF FACTOR SUBSTITUTION IN FINNISH MANUFACTURING**

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ABSTRACT: The purpose of this paper is to analyze the possibility of structural change in Finnish factor substitution relations between the energy and non-energy factors. We modify the standard generalized Leontief KLEMF cost function so that the substitution parameters related to the electricity and fuels factors may shift to new levels over time. We assume that the point of start of transition has been the year 1974 during which the first energy crises took place. The likelihood ratio tests confirm that there has indeed been a statistically significant change in energy vs. non-energy substitution. Our estimates imply stronger substitutability for most input pairs after the energy crisis.

KEYWORDS: Energy crises, cost function, parameter change

I. Introduction

Our working hypothesis is that the energy crises of the 1970's changed factor substitution relations: the time of slow energy price change and the time of fast energy price change may differ somehow with respect to the substitution between energy and the other inputs. Calculated from our data on Finnish manufacturing, the price of electricity grew during the years 1961–73 at the average rate of 2.0 % and during the period 1974–81 at the rate of 17.7 % annually. The growth rate for the price of fuels was 5.8 % before the energy crises and 28.0 % after the crises. Since the prices of the other factors have also grown much faster than before, the relative factor prices have changed much less than this. However, there was much attention to the energy situation and, as result, the firms have become more aware of the energy costs and have made efforts, often supported by the public authorities, to save energy. The energy price increase may therefore have decreased slack in the production process. Also new, less energy-intensive technology has been adopted. Therefore the way energy inputs are substituted with the other inputs may have changed. Consequently one may expect that the manufacturing industries would substitute the capital, labour and materials factors for the energy factors in a different way after the energy crises than before it. The changed substitution possibilities would have important implications to the ability of the industry to adjust to possible future energy price changes.

We will utilize a factor substitution model for the Finnish manufacturing in which certain parameters are allowed to change over time. This model allows also for the statistical testing of the structural change. Parts of the material presented here are documented in Törmä (1987). The analysis presented can be seen as an attempt to deepen the methodology of the research problem brought up recently by Hesse and Tarkka (1986) in this Journal. Their idea was to study factor substitution before and after the energy crises using pooled international cross–section and time–series data. They present substitution results also for the Finnish manufacturing (see Hesse and Tarkka 1986, 536-538). For these results it is quite critical that the computed elasticities are based on parameter estimates from pooled international data. Therefore it is assumed that the production technology is the same in every country, except for the country–specific constant terms in the input demand equations, and the error terms. This implies that, examined at equal cost shares, one assumes elasticity signs and values in different countries to be equal. Our approach is to use Finnish pooled cross–section and time–series data for the two–digit manufacturing industries.

We note that the factor substitution models estimated here differ from the model of Hesse and Tarkka also with respect to the functional form, the input structure, and the specification of the technology. Hesse and Tarkka estimated a translog model for two time periods, while we have opted for the generalized Leontief model, modified so that some parameters are allowed to change over time. We have also examined the relative contributions of parameter changes and variable (price and output) changes on the changes in elasticities.

The second difference has to do with the materials factor. Hesse and Tarkka do not consider this factor, but we do. The separation of materials from the other factors is understandable when using international data, but this choice can affect elasticity results. In both studies the energy factor has been disaggregated to electricity and fuels. The third difference deals with technical change specification. Hesse and Tarkka allow for biased technical change while we assume Hicks–neutrality. Finally, Hesse and Tarkka assume constant returns to scale, but we allow for non–homotheticity of the technology.

In section II of the paper we present the shifting Leontief model. Section III deals with the conducted estimations and tests, while section IV summarizes the noticed changes in the factor demand elasticities. The last section draws conclusions.

II. Shifting Leontief technology

The distinctive feature of our factor substitution model is that it accounts for the energy inputs, electricity and fuels, along with the primary inputs capital and labour and the materials factors. Assuming that the firms minimize costs given a predetermined level of output Q and purchase inputs at competitive prices P_i, we specify the technology using a dual cost function. For the functional form we use the nonhomothetic version of the generalized Leontief function (see Parks, 1971):

$$C = \Sigma_i \Sigma_j \alpha_{ij} (P_i P_j)^{1/2} Q + \Sigma_i \alpha_{iQ} P_i Q^2 \tag{1}$$

Factor demand equations are derived from the cost function through Shephard's lemma and take the form:

$$X_i = \alpha_{ii} Q + \Sigma_{j \neq i} \alpha_{ij} (P_j / P_i)^{1/2} Q + \alpha_{iQ} Q^2 \tag{2}$$

$$(i, j = K, L, E, M, F)$$

X_i, the demands for capital (K), labour (L), electricity (E), materials (M) and fuels (F) are functions of the relative factor prices and the output quantity. By assumption the cost function is concave in the prices and the input demand equations are homogenous and symmetric in the prices. The homogeneity condition is automatically satisfied, since the demand equations have relative input prices as explanatory variables.

Parameters α_{ij} $(i \neq j)$ are called here the substitution parameters. The symmetry condition implies that $\alpha_{ij} = \alpha_{ji}$. The sign of the substitution parameters determine whether the inputs are substitutes $(\alpha_{ij} > 0)$ or complements $(\alpha_{ij} < 0)$. If all inputs are substitutes, concavity is satisfied for all prices. If some α_{ij}'s are negative, concavity can still be satisfied for a range of input prices.

If $\alpha_{iQ} = 0$ for all i, the technology exhibits constant returns to scale. Finally, it may be noted that for econometric simplicity we have assumed Hicks–neutral technical change.

Biased technical change could have been allowed for, but the time variable would most likely be correlated with prices and output.

To be able to examine the possible structural change of the substitution relations between the energy and non–energy factors and between the two different types of energy we assume that substitution parameters α_{Ej} and α_{Fj} related to these factor relations are dependent on time. The most general structure one could consider is such that the parameters obtain separate values for each time period. In the other extreme, often structural stability is tested assuming that in two subperiods the parameters have different values but within each subperiod they remain constant. We take an intermediate view by assuming that the time path of the parameters can be approximated by the gradual switching scheme (see e.g. Bacon and Watts, 1971, Tsurumi, 1980, 1983, Tsurumi, Wago and Ilmakunnas, 1986, Broemeling and Tsurumi, 1987).

The pattern of change of the parameters is assumed to be the following. The parameter α_{ij} shifts from the level α^0_{ij} to the level α^1_{ij} over time so that the total change in the parameter value is ϵ_{ij}. The transition of the parameter value starts at time $t^\star$. The join point $t^\star$, the path from the old value to the new value, and the duration of the transition are unknown. To model these unknown elements, a transition function is applied. For example the electricity demand equation is specified in the form:

$$X_E = \alpha_{EE}Q + \Sigma_{j\neq i}\alpha_{Ej}(P_j/P_E)^{1/2}Q + \alpha_{EQ}Q^2 + \Sigma_{j\neq E}\epsilon_{Ej}trn(s_t/\eta)(P_j/P_E)^{1/2}Q, \quad (3)$$

$$(i,j = K, L, E, M, F)$$

where $trn(s_t/\eta)$ is a transition function and $s_t = 0$, when $t < t^\star$ and further $s_t = t - t^\star$, when $t > t^\star$.

The join point $t^\star$ and the parameter η, which describes the speed of the transition, are the unknown parameters to be estimated. The transition function fulfills the following conditions:

$$\lim \ trn(s_t/\eta) = 1, \ \ s \rightarrow \infty$$

$$trn(0) = 0 \tag{4}$$

$$\lim \ trn(s_t/\eta) = 1, \ \ \eta \rightarrow 0$$

These conditions imply that the mathematical form of the transition function must be such that the limit of the function is one, provided enough time passes, or when parameter η approaches zero. In the latter situation the transition is sudden and takes place during one period. If this is the case, a (0,1) dummy variable could be substituted for the transition function in equation (3). We will call the general form the transition function model and this special case the dummy variable model. There are several forms for the transition function which satisfy conditions (4). We have chosen the function:

$$trn(s_t/\eta) = 1 - \exp(-s_t/\eta), \tag{5}$$

where exp denotes exponentiation. Given this function, when η has e.g. the values 1 and 2, the whole transition takes about eight and fifteen periods, respectively. The choice of the form of the transition function is not believed to have a significant impact on the results, since experience in Tsurumi (1980, 1983) suggests that the differences between the functional forms tend to be outweighed by variability in the data.

In interpreting the results it should be kept in mind that we regard the model as an approximation to a general time–varying parameter model. Therefore we do not claim that there can be no changes in the technology after the estimated transition has ended. Rather, we are trying to find the two subperiods within which the parameters can be assumed to be fairly stable, and the period where significant instability occurs. The length of the latter period is determined by the transition speed parameter. The main interest is in finding the join point and the start of the new regime. Inference on them may, however, be sensitive to the point estimate of η, in which case it is better to consider the ranges where the beginning and end of the transition are likely to fall.

Some simplifying assumptions have been made to operationalize the model. The demand equation for fuels is similar to (3), but demand functions for capital, labour and materials have the transition function only in the coefficients of the electricity and fuels prices. Although this is a somewhat restrictive assumption, we have made it to focus attention directly on the energy vs. non–energy input substitution. Below we discuss briefly tests of a more general model.

We assume that the transition speed parameter η is the same for all the parameter transitions. This can partly be accounted for by the cross–equation symmetry restrictions $\alpha_{ij} = \alpha_{ji}$; the symmetry restrictions hold also for the transition parameters, i.e. $\epsilon_{ij} = \epsilon_{ji}$. These restrictions, implied by economic theory, were imposed in all estimations.

It is possible that in a period of transition the cost function is not stable in the sense that the theoretical static model does not hold exactly and some of the parameter restrictions are violated. It is not clear whether testing the basic restrictions is meaningful, since their rejection would imply rejection of the cost function model. On the other hand, elasticities calculated from a cost function without parameter constraints would not have the familiar interpretation. More appropriate might be a stochastic constraint approach, which allows random violations of the constraints (see Ilmakunnas 1985, 1986, Tsurumi, Wago and Ilmakunnas, 1986). This issue refers in our case only to the symmetry restriction, since homogeneity is automatically satisfied.

As noted above, the join point is unknown and hence one could try to estimate it. This would have required repeated estimations of the shifting Leontief model with different $t^\star$ years. The year which would maxize the likelihood function would then be selected. The model is nonlinear with respect to the transition parameter η and there are quite many parameters to be estimated, so to reduce computer costs we decided not to follow this possible path. So, our choice of the start of the transition remains subjective. We assume that the join point $t^\star$ is the year 1974 during which the first energy crisis took place. This choice will affect our results, but it is in accordance with our working hypothesis.

We measure factor substitution by means of the Allen elasticities of substitution:

$$\sigma_{ij} = [.5\alpha_{ij}(P_iP_j)^{-.5}Q(\Sigma_i\Sigma_j\alpha_{ij}(P_iP_j)^{.5}Q+\Sigma_i\alpha_{iQ}P_iQ^2)]/[(\alpha_{ii}Q+\Sigma_{j\neq i}\alpha_{ij}(P_j/P_i)^{.5}Q \quad (6)$$

$$+\alpha_{iQ}Q^2)(\alpha_{jj}Q + \Sigma_{i\neq j}\alpha_{ij}(P_i/P_j)^{.5}Q + \alpha_{jQ}Q^2)]$$

We have also calculated the own-price elasticities of demand:

$$E_{ii} = -.5[\Sigma_{j\neq i}\alpha_{ij}(P_j/P_i)^{.5}Q]/[\alpha_{ii}Q + \Sigma_{j\neq i}\alpha_{ij}(P_j/P_i)^{.5}Q + \alpha_{iQ}Q^2] \tag{7}$$

The substitution parameter which is used for calculating an elasticity is α_{ij} for the period before t^* and $\alpha_{ij} + \epsilon_{ij}$, when the full adjustment has taken place.

III. Estimating and testing structural change

We have been able to use the industrial data base developed during another study (Törmä and Loukola, 1985). This data has been collected for eight Finnish manufacturing industries (ISIC 31-38) for the period 1960-81; the data used in estimations is described in the Data Appendix. We used this pooled cross–section and time–series data because of the large number of parameters in the model. There are altogether 176 observations, while the shifting Leontief model with the transition function contains 28 parameters. We decided not to use industry–specific constant terms, but below we refer to some results from the dummy variable model with separate constant terms.

The input demand equations are assumed to have disturbances which are normally distributed with zero means. Across equations the errors are assumed to be contemporaneously correlated, but intertemporal correlation of the errors is ruled out. Finally, it is assumed that error variances and cross–equation error covariances stay constant over the whole sample period.

Tsurumi (1983) has shown that the gradual shifting parameter model can be estimated using either a Bayesian approach or maximum likelihood. We used the latter method. The transition function is nonlinear in the parameter η, so that the whole equation system becomes nonlinear and was estimated by the maximum likelihood method using the Davidon-Fletcher-Powell algorithm available in SHAZAM (see White, 1987).

Estimates of the substitution and transition parameters of the model are presented in

Table 1. Out of the twenty α_{ij} parameters sixteen are significant at the 5 % level; since the maximum likelihood estimates are asymptotically normal, the critical values from the standard normal distribution are used. Four out of the seven possible change parameters are significant at the 5 % level.

====== Table 1 here ==========

Judged by the signs of the α_{ij} parameters, fuels is a complement with both capital and labour. Electricity appears to be independent of capital, but a substitute with labour. However, after the change in the parameters capital and electricity are substitutes and labour and fuels are independent. The two energy forms are substitutes with each other, and also all other factor relationships show substitutability. We return to these results when analysing the elasticities and changes in them.

To test the existence of the structural change in the parameters with a likelihood ratio test, we estimated the model also in its restricted form, where the change parameters ϵ_{ij} were constrained to zeros. The test statistic, –2 log LR, where LR is the ratio of the likelihoods of the restricted and unrestricted models, was 39.648. The critical value of the χ^2 distribution with seven degrees of freedom is 18.48 for the 1 % significance level. Thus we can conclude that the null hypothesis of no parameter change can be rejected. The structural change of energy vs. non–energy factor substitution has, according to our findings, been statistically significant.

When considering this result we have to be aware of the fact that in our model only the substitution parameters related to electricity and fuels were allowed to change. This means that we ruled out the possibility of, for instance, the structural change in capital–labour substitution parameter. As will be discussed below, even in this case the non–energy–related elasticities can change, since they depend on the input demand functions and the cost function, which, in turn, depend on the change parameters of the energy–related inputs.

We estimated also a more general model, where all α_{ij} parameters were allowed to change. This involved three additional change parameters, ϵ_{KL}, ϵ_{KM}, and ϵ_{LM}. The estimates of these parameters were not significant. A likelihood ratio test statistic for testing in this general model the hypothesis that these three parameters are zeros, but the other change parameters are different from zero, was 8.04. The critical value of the χ^2 distribution with three degrees of freedom is 11.34 for the 1 % significance level, so that the hypothesis can be accepted. This gives support to our view that the source of structural change is likely to be in the energy–related parameters.

Judged by the point estimate of η, the transition has taken place during the year 1975. The speed of the change may partly be due to the use of annual data, where approximation of the transition is more difficult than in e.g. quarterly data. On the other hand, it is not uncommon to find fairly rapid changes in parameters even in models that use quarterly data (see e.g. Tsurumi, Wago and Ilmakunnas, 1986, and Ohtani and Katayama, 1986). However, data information on the length of the transition is weak, as shown by the large standard error of η. Therefore it cannot be ruled out that the actual period of parameter instability may be fairly long, and the post–1974 period is not characterized by parameter stability, in which case the estimates for the second period should be considered as averages for the unstable period. A long transition can have been caused by adjustment costs and lags in the replacement of the old capital vintages by new, less energy–intensive ones.

As noted above, the transition function reduces to a (0,1) dummy variable in the limit. Unfortunately, it is difficult to test formally the dummy variable model against the transition function model, since they are non–nested. In the case where $\eta = 0$ the likelihood function can not be defined in the period before $t^\star$, since in this period also $s_t = 0$. In principle it would be possible to formulate a more general model which includes both the dummy variable model and the transition function model as special cases.

To obtain an additional test of the structural change we estimated the dummy variable version of the factor demand equation system. The estimation was carried out using the iterative Zellner efficient (IZEF) method, which leads to maximum likelihood estimates. The model was estimated both with sectoral intercept dummies and without them. To obtain comparability to the shifting parameter Leontief model we present the latter results in Table 2, and comment on the former only in the text.

====== Table 2 here =========

When the estimates of α_{ij} are considered, main differences to the results in Table 1 are that now capital and electricity are substitutes. On the other hand, the corresponding change parameter is not significant. The two energy forms are independent of each other, and not clear substitutes as in the transition function model. However, after the parameter change they are substitutes. Also the capital–labour relationship seems to be independence rather than substitution. The other parameter estimates are fairly similar to those in Table 1. Out of the seven change parameters only one has a different sign than in Table 1, but the parameter in question is not significant in either model. When sectoral intercepts were included, the main difference to the above results was that the α_{KL} parameter was negative (although not significant), implying capital–labour complementarity.

The restricted version of the dummy variable model, where all the change parameters are zeros, has the same likelihood function as the restricted version of the shifting model. The likelihood ratio test statistic for testing the structural change was 75.204, and we can conclude that the null hypothesis of no parameter change in the dummy variable model can be rejected at the 1 % significance level.

IV. Substitution elasticities for the two regimes

Let us still examine the elasticity results obtained. The Allen elasticities of substitution and the own–price elasticities of demand obtained from the transition function model are presented in Table 3. Elasticities were calculated using the average values of prices and output in the periods 1960-73 and 1974-81. In calculating the standard errors, the fitted total cost and input demands that appear in the elasticity formulas were treated as constants.

======= Table 3 here =======

In Table 3 we also present a decomposition of the changes in elasticies to the effect of a change in the parameters, keeping the variables (prices and output) at their pre–oil crisis level, to the effect of a change in the variables, keeping the parameters at their pre–oil crisis level, and to a residual effect. [1]

Formally denote the elasticities by $\sigma(\alpha_j, v_k)$, where α denotes the parameters and v the variables and $j, k = 0, 1$ index the two time periods. Then the elasticity change is:

$$\sigma(\alpha_1, v_1) - \sigma(\alpha_0, v_0) = [\sigma(\alpha_1, v_0) - \sigma(\alpha_0, v_0)] + [\sigma(\alpha_0, v_1) - \sigma(\alpha_0, v_0)] + r, \qquad (8)$$

where the terms are the parameter change, variable change, and residual effects, respectively. The first two effects are "Laspeyres–type" decompositions, and the residual term is the difference of the "Laspeyres–type" and "Paasche–type" variable (or parameter) change effects, i.e. $r = [\sigma(\alpha_1, v_1) - \sigma(\alpha_1, v_0)] - [\sigma(\alpha_0, v_1) - \sigma(\alpha_0, v_0)]$. The decomposition can also be written in terms of the "Paasche–type" terms and a residual.

In the generalized Leontief function the sign of a substitution parameter determines whether two inputs are substitutes or complements, so that they cannot switch from substitutes to complements or vice versa because of the variable change effect alone. It should

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[1] *We are thankful to a referee for clarifying this decomposition.*

be noted that in an empirical application the true parameters are unknown and instead of α_j the estimated parameters $\hat{\alpha_j}$ are used, which, however, depend on the data. In this sense the first term of the decomposition in the table is not a "pure" parameter change effect. We feel, however, that this decomposition is informative of the relative contributions of different factors on the changes in elasticities.

The results show that capital and electricity have changed from independent inputs to substitutes; this is mainly due to the parameter change effect. Capital–fuels complementarity has increased mainly because of the variable change effect. Both labor–electricity substitutability and labor–fuels complementarity have decreased due to parameter changes. In both cases the variable change effect is actually contrary to the parameter change effect.

The substitutability of the two energy forms has increased, which follows completely from the parameter changes. The materials–fuels substitutability has greatly reduced as a result of both the parameter and variable change effects. Capital–labour substitution elasticity has increased, which results from the variable change effect.

We interpret larger positive elasticities (i.e. greater substitutability) and smaller in absolute value negative elasticities (i.e. smaller complementarity) as indicators of increased substitution possibilities after the energy crisis. For most input pairs, the substitution possibilities have increased or there is only very small change in their relationship. The main exceptions are the labor–electricity and materials–fuels relationships. In most cases the increased substitutability follows from the parameter changes, since the variable change effects tend to be in the opposite direction.

The own–price elasticity of capital has slightly increased in absolute value and is significant after the change, which has been caused by parameter changes. For labour, electricity and materials the own–price elasticities are either the same or have changed very little. The own–price elasticity of fuels has the wrong sign before the parameter change, but is negative after it; both elasticities are, however, non–significant. The positive sign of this elasticity implies that concavity of the cost function does not hold when evaluated at old parameters and the average prices and output for the pre–oil crisis period. Although the own price elasticities have the right signs in the second period, concavity was found to be violated also in this case.

The dummy variable model gives for the most part results that are very similar to those from the transition function model. The results are shown in Table 4. The main differences to Table 3 are the following. Capital and electricity are substitutes even before the energy crisis, and capital–fuels complementarity has slightly decreased over time. The two energy forms are independent before the energy crisis, but clear substitutes after it; this change in the elasticity comes from the parameter change effect. The capital–labour relationship appears to be independence rather than substitution. Finally, the own–price elasticity of fuels has the correct sign, although the parameter is not significant. On the other hand, capital has a positive, but non–significant own–price elasticity before the energy crisis. Also in the dummy variable case concavity of the cost function was violated when evaluated at the average prices and output of the two regimes.

====== Table 4 here =====

V. Conclusions

In this paper we have analyzed the possibility of structural change in Finnish factor substitution between the energy and non–energy factors and between the two energy forms, electricity and fuels. The likelihood ratio tests confirmed that there has indeed been a statistically significant change in energy vs. non–energy substitution. Our results indicate that there has been a change towards greater substitutability or decreased complementarity for most input pairs. According to our estimates this change has taken place rapidly, during one year. However, data information on the length of the transition is weak and a considerably longer period of parameter instability cannot be ruled out.

We have assumed that there has been only one shift in the cost function. However, after the second oil crisis there may have been another shift, although it might not be possible to separately identify the two changes. This may partly explain our results on the length of the transition.

It is worth mentioning that we have analyzed the same research problem by dividing the two–digit industries according to their energy intensiveness. This has been reported in Törmä (1985). The conclusion was that a structural change has taken place in both low and high energy intensive industries. This result was based on a dummy variable version of the Leontief model.

Let us end this analysis by comparing the structural change results obtained here with the results obtained by Hesse and Tarkka (1986). The two studies give differing results as to the signs of the elasticities. The data, input structures and specification of the technology differ, however, to such an extent that we cannot really compare the signs of the elasticities, nor their absolute values. We will, however, compare the idea the two studies give about the directions of the structural change of factor substitution.

Of the six substitution elasticities that have been estimated in both studies, the same direction of change is found in four cases (three if the dummy variable model is used). For the own–price elasticities the directions of change are mostly different. It should be noted that this comparison is only indicative, since neither study tests whether changes in the elasticities are significant. We have tested only the significance of the parameter change effects, whereas Hesse and Tarkka do not present formal stability tests.

There is another study, Hall (1986), that deals with structural change in energy substitution. Hall's approach deviates from ours since he studies the possibility of structural change between the following energy forms: petroleum products, gas, coal and electricity, using a translog model and pooled international data for the period 1960-82. According to his F–tests one cannot reject structural breaks in individual equations immediately following each of the two major oil price shocks. Hall's tests show that results for 1960–82 need not be representative of those for the sub–periods.

The results of Hall are not inconsistent with our finding that electricity and fuels are more substitutable after the energy crises. Hall's estimate for the international cross price elasticity between the electricity and petroleum products is zero for the period 1960–82 and 0.12 for the period 1974–82. These estimates correspond to our estimates for the electricity–fuels cross–price elasticity: .01 and .16 for the periods 1960-73 and 1974-81, respectively, calculated from the dummy variable model. The results of Hall also imply that this substitutability has become even stronger over the second energy crisis since the value of the cross price elasticity is 0.19 for the period 1974-78 and 0.33 for the period 1979-82.

Finally, we should mention some reservations to the approach used for studying structural change. We have used a static model, where capital is treated analogously to the other inputs. If capital is fixed in the short run, and there are costs of adjusting the capital stock, the firms' ability to react to energy price shocks might be different. Another issue that is encountered when dynamics is taken into account is that it is likely that the energy price shocks have influenced the expectations of the firms with respect to future input prices and output. If the true model is static, this does not matter, since the firms can in every period choose the inputs optimally. If expectation formation is explicitly modelled in a rational expectations framework, the parameters of the factor demand system are nonlinear functions of technological parameters and parameters that describe the processes that determine input prices and output. Hence, if a dynamic model is erroneously specified as static, the estimated structural change may in reality be due to a change in expectations, a change in technology, or both. Modelling the expectations in a dynamic model would allow separate identification of these effects.

Energy price changes may have caused measurement problems in the variables (see Berndt and Wood, 1986). It is likely that the energy crises have caused premature scrapping of energy–intensive capital stock. The available statistics are based on average lifetimes of the capital items and may therefore give an upward biased measure of capital input. Also the output measure may be misleading, since energy price changes may have had a significant impact on the output mix within the industrial sectors.

DATA APPENDIX

Capital input is measured by the net capital stock in constant prices. The user cost of capital is based on the theory presented in Ylä–Liedenpohja (1983); see Törmä, Savolainen and Väisänen (1985).

Labour input is measured by working hours. Its price is the sum of salaries and the social security contributions of the employers divided by the number of hours worked.

As the price of materials we used the price indices of the imported materials. We thus make an implicit assumption that the domestic and foreign materials are perfect substitutes, so that their prices are the same. The quantity of materials is the value of materials used divided by the price of the imported materials.

The prices of five energy categories, electricity, heat energy, light and heavy fuel oil and coal, were calculated from quantity and value data and are expressed as FIM per equivalent oil ton. The quantity and the price of the fuels aggregate, which includes the four last categories, were obtained as Divisia–Törnqvist indices.

The output volume is the gross production value deflated by the production price index. All data were scaled so that their values in 1960 are 1.0.

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	α_{ij} parameters	ε_{ij} parameters	$\alpha_{ij} + \varepsilon_{ij}$
K-K	1.117 *** (.083)		
K-L	.095 ** (.042)		
K-E	-.004 (.084)	.189 * (.106)	.185 ** (.090)
K-M	.122 (.105)		
K-F	-.157 * (.091)	-.055 (.086)	-.212 *** (.080)
L-L	.224 *** (.052)		
L-E	.421 *** (.062)	-.242 *** (.076)	.179 ** (.073)
L-M	.456 *** (.067)		
L-F	-.230 *** (.070)	.165 *** (.059)	-.065 (.056)
E-E	-.365 *** (.118)		
E-M	.672 *** (.122)	.147 (.126)	.819 *** (.110)
E-F	.172 ** (.080)	.151*** (.047)	.323 *** (.072)
M-M	-.703 *** (.201)		
M-F	.252 (.158)	-.235 ** (.106)	.017 (.130)
F-F	.934 *** (.169)		

	α_{iQ} parameters
K-Q	-.095 *** (.013)
L-Q	-.048 *** (.004)
E-Q	-.070 *** (.010)
M-Q	.049 *** (.015)
F-Q	-.105 *** (.014)

	Transition speed parameter
η	.043 (1.000)

Log likelihood -364.180

Standard errors in parentheses
* significant at 10 % level
** significant at 5 % level
*** significant at 1 % level

Table 1: Parameter estimates from the transition function model

	α_{ij} parameters	ε_{ij} parameters	$\alpha_{ij} + \varepsilon_{ij}$
K-K	1.255***		
	(.076)		
K-L	.057		
	(.037)		
K-E	.165 *	.052	.217 ***
	(.091)	(.100)	(.065)
K-M	.022		
	(.086)		
K-F	-.289 ***	.079	-.210 ***
	(.109)	(.088)	(.077)
L-L	.206 ***		
	(.042)		
L-E	.458 ***	-.241 ***	.217 ***
	(.055)	(.072)	(.060)
L-M	.417 ***		
	(.054)		
L-F	-.154 **	.130 **	-.024
	(.075)	(.059)	(.052)
E-E	-.394 ***		
	(.103)		
E-M	.636 ***	.173	.809 ***
	(.118)	(.122)	(.084)
E-F	.017	.247 ***	.264 ***
	(.083)	(.053)	(.069)
M-M	-.803 ***		
	(.159)		
M-F	.574 ***	-.392 ***	.182
	(.162)	(.108)	(.118)
F-F	.767 ***		
	(.170)		

	α_{iQ} parameters
K-Q	-.097 ***
	(.012)
L-Q	-.048 ***
	(.003)
E-Q	-.067 ***
	(.009)
M-Q	.056 ***
	(.013)
F-Q	-.100 ***
	(.013)

Log likelihood -346.402

Standards errors in parentheses
* significant at 10 % level
** significant at 5 % level
*** significant at 1 % level

Table 2: Parameter estimates from the dummy variable model

Allen elasticities of substitution	1960-73 old parameters	1974-81 new parameters	Decomposition of change in elasticity		
			Parameters change effect	Variable change effect	Residual effect
K-L	.24*** (.11)	.36*** (.16)	.00	.14	-.02
K-E	-.01 (.20)	.45** (.22)	.36	.00	.10
K-M	.29 (.25)	.31 (.27)	.01	.00	.01
K-F	-.51* (.29)	-.73*** (.28)	-.07	-.19	.04
L-E	1.16*** (.17)	.55** (.22)	-.70	.22	-.13
L-M	1.26*** (.18)	1.49*** (.22)	.29	-.04	-.02
L-F	-.85*** (.26)	-.28 (.24)	.61	-.28	.24
E-M	1.74*** (.32)	1.73*** (.23)	.34	-.41	.06
E-F	.60** (.28)	.91*** (.20)	.31	.02	-.02
M-F	.88 (.55)	.05 (.39)	-.82	-.14	.13
Own price elasticities					
K-K	-.04 (.08)	-.09** (.04)	-.05	.00	.00
L-L	-.39*** (.04)	-.41*** (.05)	.00	-.03	.01
E-E	-.73*** (.05)	-.73*** (.06)	.03	-.03	.00
M-M	-.83*** (.10)	-.75*** (.10)	-.04	.11	.01
F-F	.03 (.11)	-.01 (.10)	-.04	.05	-.05

Standard errors in parentheses
* significant at 10 % level
** significant at 5 % level
*** significant at 1 % level

Table 3: Elasticities from the transition function model

Allen elasticities of substitution	1960-73 old parameters	1974-81 new parameters	Decomposition of change in elasticity		
			Parameters change effect	Variable change effect	Residual effect
K-L	.14	.21	.00	.10	-.03
	(.09)	(.16)			
K-E	.40*	.52***	.00	.14	-.02
	(.22)	(.16)			
K-M	.05	.06	.01	.00	.00
	(.20)	(.27)			
K-F	-.95***	-.73***	.40	-.47	.29
	(.36)	(.27)			
L-E	1.26***	.68***	-.69	.26	-.15
	(.15)	(.19)			
L-M	1.10***	1.40***	.48	-.18	.00
	(.14)	(.22)			
L-F	-.57**	-.11	.48	-.20	.18
	(.28)	(.23)			
E-M	1.59***	1.74***	.66	-.41	-.10
	(.29)	(.18)			
E-F	.06	.76***	.66	.01	.03
	(.29)	(.20)			
M-F	1.95***	.95***	-1.23	-.36	.59
	(.55)	(.37)			
Own price elasticities					
K-K	.02	-.02	-.06	.05	-.03
	(.03)	(.06)			
L-L	-.41***	-.43***	.01	-.03	.00
	(.03)	(.04)			
E-E	-.74***	-.74***	.03	-.04	.01
	(.04)	(.03)			
M-M	-.86***	-.79***	-.10	.14	.03
	(.08)	(.08)			
F-F	-.08	-.12	-.04	.03	-.03
	(.11)	(.12)			

Standard errors in parentheses
*   significant at 10 % level
**   significant at 5 % level
*** significant at 1 % level

Table 4: Elasticities from the dummy variable model

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