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Estimating and Testing CES Production Functions on Irish 12-Sector Input-Output Data

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Abstract: Irish input-output data are used to estimate and test CES production functions for each of 12 sectors having 2 groups of input costs. The objective is to generalise input-output analysis to allow for price effects and technical change. However, the CES model is not found compatible with the data and, indeed, is less so than the traditional Leontief model. The analysis indicated the desirability of looking at alternative models, but the paucity of data prevented this.

I INTRODUCTION

Input-output (I-O) analysis is an extensively employed tool of economics. However, the production function embedded within traditional input-output analysis – Leontief if input-output ratios are assumed constant in volume terms, or Cobb-Douglas if ratios are assumed constant in value terms – is restrictive in many respects. Since both Leontief and Cobb-Douglas forms are special cases of CES functions, it seems desirable to have the capacity to use production functions corresponding to this class to generalise input-output analysis. De Boer (1982) has discussed the appropriate methodology in detail and one purpose of this paper is to apply his procedures to Irish data.

The virtues of the CES production function relative to the more restricted forms are that relative price effects and technical change can be allowed for. However, the CES production function can itself be criticised as restrictive and much more general functional forms are (in theory) preferable. Thus

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recent investigations of production functions for Irish economic sectors including papers by Higgins (1981) and Boyle and Sloane (1982) have used the translog cost function. Higgins estimated the degree of substitution between capital services, labour, materials, and fuel, for sectors processing meat and milk within the Irish food industry, using data series from 1953-1973. The responsiveness of these inputs to price changes was also estimated. Capital services and labour were found to be strong substitutes in production in all sectors. He generally concluded the technology of production was not consistent with the commonly used Cobb-Douglas or CES production functions. Boyle and Sloane estimated factor-demand cost functions for each of 40 manufacturing industries. The factors demanded were capital services and two types of labour, namely wage-earners and salaried workers. Data covered the period 1953-1973. The factor-demand equations were estimated both inclusive and exclusive of a trend factor, to discern the influence of technical change. The results suggested that technical change was non-neutral. The elasticity estimates were substantially reduced for the specification including time. It was found that the elasticity of substitution between production workers and capital was greater than the corresponding elasticity for non-production workers and capital.

However, the functions that can be estimated within particular sectors are much more elaborate than what is achievable at inter-industry level. Construction of input-output tables imposes heavy data demands and consequently the number of usable observations is small, at least in the sense of time points. De Boer's (1982) approach does offer, at least a partial, solution by assuming certain parameters in production functions constant across some sectors and employing simultaneous estimation. Thus the degrees of freedom for estimation and tests are increased, although the price is the acceptance of assumptions to be described later.

Indeed, an important empirical advantage of traditional input-output relations is their relative simplicity and consequent estimability. Even the incorporation of CES functions represents an order of magnitude escalation in the data demands. So another objective of this paper is to test if, having fitted CES functions, the resulting model is an appreciably more appropriate representation than the traditional Leontief one. De Boer's methodology provides for such tests.

The practical application of de Boer's theory and methodology used 19-year data for the Netherlands for each year 1949-1967 which gave 18 year-to-year changes. The CES production function of sector j described by him in a neo-classical theoretical framework relates real input costs at sector level i to real gross output, relative prices and trend. For each input cost i, its real growth rate is explained by the growth rates of real gross output j and of relative price i, and by a trend term (Hicksian neutral technical change). A single set of three parameters (β) is to explain each input i of sector j. So simultaneous estimation of the equation parameters (for example, by Maximum Likelihood) for each sector j is feasible.

What follows describes similar modelling procedures with Irish data, but unfortunately with fewer available time points. Eight 12-sector I-O transactions tables were derived from extant tables (both published and unpublished) to form the database. For the estimation the input costs were combined into two groups for each of the 12 sectors: (1) total domestic (Irish-produced) goods and services; (2) total imported goods and services. But repricing was done at sector level for domestic, and distinguishing energy types among the imports, in preparing the data so as to be valued at constant prices. Further description is given in Section III.

Section II briefly treats the relevant theory, taking only the necessary minimum from de Boer. Section III summarises the data preparations which culminate in the growth-rate annual averages used for the regressions. Section IV gives econometric results and compares the CES model with the Leontief model. Section V draws some conclusions.

II THE MODEL

The linearised version of de Boer's exact infinitesimal logarithmic function has the following form for sector j:

$$\tilde{x}_{ij} = \beta_{1j}\tilde{y}_j + \beta_{2j}r_{ij} + \beta_{3j} + \epsilon_{ij} \tag{1}$$

where

$\tilde{x}_{ij}$ is the growth-rate of input i to sector j, based on last year (year − 1), at last year's prices.

β_{1j} is the inverse of the degree of homogeneity of the CES production function h_j^{-1} of sector j; this is necessarily positive by definition.

$\tilde{y}_j$ is the growth-rate of gross output of sector j at last year's prices.

β_{2j} is the Allen elasticity of substitution σ_{1j} between the intermediate inputs of sector j, positive by definition; there are M such inputs in all, so in Irish data below M = 2, for i values 1 and 2, and imports are treated as intermediate.

β_{3j} a constant growth-rate term η_j, namely Hicksian generalised neutral technical change of sector j, expected to be positive.

ϵ_{ij} an error term, to explain the remainder of input i to sector j.

r_{ij} the relative price effect ij is

$$\sum_{m=1}^{M} w_{mj}(-1)\tilde{p}_m - \tilde{p}_i,$$

for

$w_{mj}(-1)$ last year's relative weight of intermediate input m among the M, with all M having an aggregate unit weight.

$\tilde{p}_m$ price index of input m, based on unity for last year.

$\tilde{p}_i$ similar, for input i. Thus the relative price effect is the difference between the weighted price index of all intermediate inputs and the particular price index of input i.

Thus it is clear that the parameters β_{1j}, β_{2j} and β_{3j} are invariant across input sectors i of (output) sector j. These parameters are to be estimated, given time series for $\tilde{x}_i$, for $\tilde{y}_j$, for the relative price effect r_{ij}, and for the implicit unit vector coefficient to the η_j, in each sector j. Note that for $h_j = 1$, $\sigma_{1j} = 0$, $\eta_j = 0$, Equation (1) becomes the familiar Leontief model.

The annual growth rates, even on a year-by-year basis, are imprecise in applying a linear approximation to the exact infinitesimal logarithmic relationship. The Irish data include average annual growth-rates derived from time-spans of 2 to 8 years; this aspect therefore implies further imprecision due to structural changes which would not happen so much in a year-by-year comparison.

Obviously, a less constrained model is

$$\tilde{x}_{1j} = \beta_{11j}\tilde{y}_j + \beta_{12j}r_{1j} + \beta_{13j} + \epsilon_{1j} \quad (2)$$

$$\tilde{x}_{2j} = \beta_{21j}\tilde{y}_j + \beta_{22j}r_{2j} + \beta_{23j} + \epsilon_{2j} \quad (3)$$

where input 1 is total domestic goods and services and input 2 is total imported goods and services.

It is to be noted also that the sum of these two input groups is less than total input: the residue of total input comprises Gross Domestic Product (GDP). There is therefore no implicit accounting constraint to prevent these two input groups having differing growth rates, each also differing from that of total input (same as gross output). However, a greater number of distinct parameters implies fewer degrees of freedom for estimation.

Equation (1) can be obtained by specifying three constraints or restrictions on the estimation process:

$$\beta_{11j} = \beta_{21j} \quad (4)$$

$$\beta_{12j} = \beta_{22j} \quad (5)$$

$$\beta_{13j} = \beta_{23j} \quad (6)$$

The restrictiveness of the production function specification implied by the CES tests is to be noted. First, the specification implies separability between intermediate and non-intermediate inputs. Second, aggregation is performed over several intermediate inputs to obtain two inputs: (i) domestic and (ii) imported goods and services. The theoretical implications of these restrictions need to be balanced against the real-world difficulties of making production functions operationally manageable.

De Boer remarks that the separability assumption implies in general a two-level CES production function of the form given by Sato (1967). The latter admits that the very substantial degree of aggregation essential for operational feasibility, and the corresponding separability assumptions, may detract from a model's representation of reality, but he argues that resulting biases are relatively small, especially if technical change is neutral with respect to capacity. Such assumptions are made in any event when aggregating production functions of individual firms so as to achieve a production function for a whole industry.

The Model tested on Irish data corresponds to Model 3 of de Boer (p. 86) which is an homogeneous one-level CES function with gross value of production as measure for output, and with generalised Hicksian neutral technical change. The CES model being tested on the Irish data considers two sub-groups of intermediate inputs and ignores primary inputs, thus concentrating attention on the intermediate structure. In I-O analysis intermediate inputs as such are a recognised input group, separable from primary inputs, the latter generally recognised as a further group. Since limited numbers of observations create econometric problems, aggregation of input groups is required for estimation, at the expense of abandoning some theoretical refinement. Let us consider the choice of aggregate domestic goods and services as one intermediate input, with their imported counterparts as the other such input. We may find some analogy with costs of labour compared with costs of capital in the primary input group. Both labour and capital are required for the production process. In the short term a limited amount of substitution is possible, depending on cost minimisation. Similarly, both domestic and imported goods and services are typically required in each sector, at least in Irish conditions. Some substitution is possible, to help reduce costs, but large portions of both are not substitutes: agricultural resources and most services, on the domestic side; non-competitive imports on the import side.

One may argue for improved "separability" of the two groups of intermediate inputs, if "imports" were confined to the non-competitive kinds, and competitive imports were combined with domestic goods and services. But the behaviour of total imports is of great significance in the context of Irish economic activity; thus an input group comprising all imports would be one form of aggregate grouping, in any similar production function analysis of Irish data.

It will be seen at the beginning of Section IV that there were at most 7 usable observations for each sector. So, although the basic transactions tables have 12 sectors, it is impossible to try modelling the 12 intermediate input groups. Selected as two input groups are the domestic and imported goods and services. A third group, although not included for estimation purposes, is in fact the aggregate primary input cost. There is little choice beyond this.

III DATA PREPARATIONS

Eight 12-sector I-O transactions tables comprised the basic data; these were for the years 1956, 1964, 1968, 1969, 1974, 1976, 1978, 1982. Extant tables, both published and unpublished, were reworked or modified to show the 12 sectors listed in Table 1 below. Among the published tables used are those for 1969 (Central Statistics Office, 1978) and for 1976 (Henry, 1980).

Repricing of transactions is required, for measurement of gross output volume changes, and of composite price indices. The seven tables 1956 to 1978 need to be repriced at prices of the next table ahead, for example, 1956 at 1964 prices, 1978 at 1982 prices. Thus a weighted price index of inter-industry 1956 inputs at 1964 prices is available, and of 1978 inter-industry at 1982 prices is available, as the quotient of the aggregate repriced value by the aggregate original value. Each sector input row has its own price index.

Likewise, the seven tables 1964 to 1982 need repricing at prices of the last table before, for example, 1964 at 1956 prices and 1982 at 1978 prices. Thus volume growth of total input (same as gross output) at base-year prices for each successive pair of tables can be calculated, for example, 1956 and 1964, 1978 and 1982. For all volume growths and price indices relating to a time span of several years, the geometric annual average growth rate was derived and shown in percentage form.

In repricing the transactions, say of year 1976, it should be made clear why pricing at previous (1974) table's prices and following (1978) table's prices are both required. The 1976 table at 1974 prices is compared with 1974 actual to give sector volume changes 1974-76 based on 1974. The 1976 table at 1978 prices will be compared with 1976 actual to give sector price changes 1976-78 based on 1976 and 1976 weightings. By these two repricings of 1976 transactions it is therefore possible to find a 1974-weighted volume growth of each sector for 1974-76, and a 1976-weighted price change of

Table 1: *Estimates Without Constraints*

I-O Sector and Input	Number of observations	Coefficient Estimates β_1 (h^{-1})	β_2 (σ_1)	β_3 (intercept) (η)
	(1)	(2)	(3)	(4)
(1) Energy, domestic	5	1.84	-0.35	-1.50
imported	5	1.68	-0.21	-0.83
(2) Agriculture, etc. domestic	4	2.00	-30.46	-0.01
imported	4	-2.58	-13.01	16.21
(3) Food, etc., domestic	6	1.03**	1.03	-0.11
imported	6	0.65	-2.88	4.27
(4) Clothing, etc., domestic	5	1.03*	-4.21	-5.91
imported	5	1.48*	-5.29	4.83
(5) Wood, etc., domestic	5	0.11	4.40	6.31
imported	5	1.00	4.64	-3.26
(6) Chemicals, etc., domestic	5	1.43	1.14	-1.54
imported	5	1.18	-3.49	-3.73
(7) Clay, etc., domestic	4	1.38*	2.57	0.89
imported	4	1.09	-0.86	-1.69
(8) Engineering, domestic	6	1.03**	-1.07	-1.66
imported	6	1.72**	-12.21*	-0.03
(9) Construction, domestic	5	1.83**	-2.03	-4.78
imported	5	1.28	-2.00	4.95
(10) Transport, domestic	4	3.07**	-0.57*	-12.19**
imported	4	-0.41	0.15	7.17
(11) Trade, etc., domestic	4	5.49	10.20	-23.31
imported	4	8.64	-8.91	-52.78
(12) Artificial, domestic	5	1.00**	9.06	1.18
imported	5	1.41**	5.00	-0.43

*Significant at 5 per cent level.
**Significant at 1 per cent level.

each sector for 1976-78. An attempt is thus made to approach the de Boer weighting system implied by Equation (1) and its background, as closely as possible.

The repricing is done through inflation or deflation of the primary inputs, consistently applied to inter-industry (same as intermediate) inputs by means of the Leontief Inverse. The system and model used are explained in detail in

Henry (1986, pp. 104-105) and need not be repeated here. Each repricing of primary inputs gives as the final result a set of 12 price indices of domestic sector gross outputs to base unity for whatever year is chosen as base. The primary inputs can be detailed as required, or as relevant: imports (of several kinds), indirect taxes, subsidies, wages, profits, depreciation, or any reworking or re-arrangement of these that might occur.

The general deflators (or inflators) applied to the primary inputs are derived from tables such as A5 and A6 of Central Statistics Office (1985) and earlier issues. Personal expenditure at current and at constant prices provides an implicit price index for deflation of wages (or household income). Expenditure by the public authorities provides a price index applicable to indirect taxes and subsidies. The implicit deflator of capital formation is applied to profits and depreciation, except for "profits" income of farming, for which the personal expenditure deflator was considered more appropriate. This choice of deflators uses the "buying power" principle: after deflation what buying power would the wages, or profits, or government income (used by government to purchase goods and services) have? Energy imports have shown extraordinary price inflation since 1973; for this reason they have been detailed for repricing purposes in the 1969 and later tables. The basic data on 1982 quantities and values appear in Central Statistics Office (1983); earlier issues give details of energy imports of earlier years.

It may occur to the reader that there is considerable scope for imprecision inherent in this method of repricing. Because of the time-span 1956-1982 of the I-O tables, a considerable amount of constant price re-basing of national accounts will have taken place. A degree of arbitrariness, therefore, creeps into selecting appropriate price deflators from which to derive average annual price change. For instance the 1982/1978 price deflator of personal expenditure is 1.86 if based on the series at 1975 prices, but 1.89 if based on that at 1980 prices. Corresponding deflators for government current expenditure are 1.88 and 1.95, respectively. While such differences may occur, they are unlikely to affect the results of testing the model. The more information one uses, both by way of number of sectors and detail of primary inputs, the better the estimate of the repriced transactions. These are, in any case, combined into two groups for CES purposes, after repricing:

(1) total domestic inter-industry, namely the sum of transactions in rows (1) to (12) of each column, comprising Irish-produced goods and services;

(2) total imports of goods and services. The repriced GDP items (indirect taxes, wages, profits, etc.) are not used further, in the CES estimation process.

It may finally be stated that a large volume of data preparation (including 8 I-O transaction tables) underlies the set of values used as basic data for model estimation. These basic observations are available to interested readers, on request.

IV RESULTS

In the estimation some observations were detected as outliers[1] during the trial runs of the regressions. This was not an unexpected finding because in the small Irish economy disruptive effects (for example, due to large-scale industrial action) can easily appear in at least some sector in some year. These observations were omitted from subsequent analyses. The actual numbers of observations are shown in Table 1 giving the results of analyses.

Table 1 also shows the estimates for Equations (2) and (3), where the constraints (4), (5) and (6) have not been applied. If the numbers of observations were larger these estimates would be very interesting since they would permit testing the plausibility of the constraints (4), (5) and (6). Some of the pairs of estimates do seem to differ substantially, but perhaps because the degrees of freedom are so few this is not borne out by statistical significance tests. In fact, most of the coefficients in Table 1 are not even significantly different from zero. Of course, if a Leontief model was strictly correct the β_2 coefficients should be zero and the β_1 equal to unity. Actually 10 of the 13 statistically significant coefficients are in the β_1 column, but the error degrees of freedom are far too few to make much of this result.

Any useful statistical criteria must be based on the estimates of Equation (1) where the combination of sectors – via the constraints – increases the error degrees of freedom. The estimates which were obtained by an iterative SURE procedure are given in Table 2. The tests of the β_2 coefficients gave statistically significant results for 9 out of the 12 sectors. Since these coefficients ought to be zero on a strict Leontief model, the statistical tests do provide evidence of the desirability of a more elaborate framework. But it is not at all clear what that should be. The CES model also lacks plausibility. Examination of the sectors of significance shows only 2 having all three coefficients positive, an essential feature of the CES model, as detailed in Section II above. The two sectors having all positive coefficients are (5) wood etc. and (7) clay, etc. Other sectors show significantly *negative* β_2 coefficients

1. The SHAZAM econometric computer package of K.J. White (1978) was used for estimation. The writer (Henry) chose as outliers observations showing a calculated error of the dependent variable (given by the predicted value less the observed value) numerically at least twice the average absolute error of remaining observations.

Table 2: *Results for the CES Model, Equation (1)*

I-O Sector and Input	*Coefficient Estimates* β_1 (h^{-1}) (1)	β_2 (σ_1) (2)	β_3 *(intercept)* (η) (3)
(1) Energy, domestic	1.84**	-0.34	-1.49
imported	,,	,,	,,
(2) Agriculture, etc., domestic	5.06**	-18.10**	-9.74**
imported	,,	,,	,,
(3) Food, etc., domestic	1.05**	-0.005	-0.43
imported	,,	,,	,,
(4) Clothing, etc., domestic	1.15**	-1.26*	-1.43*
imported	,,	,,	,,
(5) Wood, etc., domestic	0.62**	5.60**	0.78**
imported	,,	,,	,,
(6) Chemicals, etc., domestic	1.16**	-2.52**	-4.36
imported	,,	,,	,,
(7) Clay, etc., domestic	1.41**	4.75**	0.26**
imported	,,	,,	,,
(8) Engineering, domestic	1.62**	-0.30	-4.51**
imported	,,	,,	,,
(9) Construction, domestic	2.14**	-2.52**	-10.93**
imported	,,	,,	,,
(10) Transport, domestic	2.99**	-0.62**	-11.78**
imported	,,	,,	,,
(11) Trade, etc., domestic	6.14**	-2.89**	-23.23**
imported	,,	,,	,,
(12) Artificial, domestic	1.19**	6.76**	-1.02**
imported	,,	,,	,,

*Significant at 5 per cent level.
**Significant at 1 per cent level.

implying that the data would reject the hypothesis of positive β_2 (the CES model) at an even higher level of significance than that of zero β_2 (the Leontief model). The convention in econometrics when a theoretically positive parameter is estimated as negative is to take it as zero. In this context this amounts to accepting a Leontief form. Some reservations about the interpretation of tests are probably in order, given that the assumed constraints were not really testable. However, even if the pairs of β_2 coefficients could differ so that the data estimates some amalgam of them, a CES context should imply both positive so that the negative estimate is still contradictory.

Probably the most plausible implication is that neither Leontief nor CES adequately represent the situation and, ideally, more detailed analysis should be undertaken. The problem is that the number of observations are insufficient for such an investigation.

The tests just discussed suggest that the Leontief form is no worse a fit to the data – except for the wood and clay sectors – than is the CES. More correctly, since the Leontief is a special case of the CES, the data do not support any form of CES, but disagree least with the Leontief form. But Leontief models also imply β_1 equal to unity and β_3 zero. Table 3 gives the estimates of coefficients – estimated separately for domestic and imported – and 95 per cent confidence intervals for β_1 and β_3. Since the degrees of freedom are so small these confidence intervals are often very wide. Thus the tests – "Do the intervals for β_1 and β_3 contain unity and zero respectively?" – are not very demanding. However, it is obviously better to find values inside the intervals than outside them and this is generally the case. In 20 out of 24 intervals for β_1 unity is included, and in 22 out of 24 intervals for β_3, zero is included.

V SUMMARY OF CONCLUSIONS

The paucity of Irish data does not permit a very wide-ranging investigation of forms of production function in an input-output context. When supplemented by some restrictions on parameters, it does permit the estimation and testing of a CES-type model. This, if an adequate fit, would have advantages over the Leontief form in allowing for price effects and technical change. Unfortunately, except for 2 out of 12 input-output sectors, the CES model is contradicted by the data. So is the Leontief, though not as drastically. It seems that substantial improvements on Leontief forms of production function in input-output analysis must await further availability of data.

Table 3: *Test for Leontief Model*

I-O Sector and Input	β_1 Coefficient (h^{-1})		β_3 Intercept (η)	
	Estimated Value	*95% Confidence Interval*	*Estimated Value*	*95% Confidence Interval*
(1) Energy, domestic	1.91	0.51 to 3.31	-2.11	-8.38 to 4.16
imported	1.66	-0.19 to 3.51	-0.62	-8.91 to 7.67
(2) Agriculture, etc., domestic	1.83	-0.29 to 3.95	3.47	-13.55 to 20.49
imported	-1.71	-8.36 to 4.94	9.90	-43.46 to 63.26
(3) Food, etc., domestic	1.04	0.97 to 1.11	-0.45	-0.98 to 0.08
imported	0.93	0.01 to 1.85	-1.31	-9.82 to 7.20
(4) Clothing, etc., domestic	1.00	0.00 to 2.00	-1.47	-8.68 to 5.74
imported	1.39	0.68 to 2.10	0.04	-5.07 to 5.15
(5) Wood, etc., domestic	0.22	-0.66 to 1.10	3.80	-8.47 to 16.07
imported	0.92	0.22 to 1.62	-0.64	-10.41 to 9.13
(6) Chemicals, etc., domestic	1.39	0.06 to 2.72	-2.51	-13.96 to 8.94
imported	1.10	0.04 to 2.16	-5.95	-15.01 to 3.11
(7) Clay, etc., domestic	1.42	0.71 to 2.13	0.04	-3.89 to 3.97
imported	1.20	-0.27 to 2.67	-2.60	-10.71 to 5.51
(8) Engineering, domestic	1.00	0.57 to 1.43	-0.35	-6.06 to 5.36
imported	1.86*	1.21 to 2.51	-6.17	-14.73 to 2.39
(9) Construction, domestic	1.80*	1.29 to 2.31	-3.90**	-6.11 to -1.69
imported	1.27	-1.02 to 3.56	1.75	-8.21 to 11.71
(10) Transport, domestic	3.12*	2.63 to 3.61	-12.56**	-15.94 to -9.18
imported	-0.37*	-1.46 to 0.72	6.76	-0.80 to 14.32
(11) Trade, etc., domestic	3.68	-0.84 to 8.20	-14.25	-35.49 to 6.99
imported	-9.52	-33.34 to 14.30	47.02	-64.96 to 159.00
(12) Artificial, domestic	1.16	0.61 to 1.71	-3.78	-12.68 to 5.12
imported	1.35	0.79 to 1.91	5.80	-3.27 to 14.87

*Not acceptable, its confidence interval excludes 1.0.
**Not acceptable, its confidence interval excludes 0.0.

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