INTER - FUEL SUBSTITUTION, ENERGY DEMAND and

EMBODIED TECHNICAL CHANGE

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Abstract: This paper describes final energy demand for different fuels at a disaggregated level of 12 activities of the economy plus households. The model used combines single equations for total final energy demand with translog functions for inter – fuel substitution. At both stages embodied and un – embodied technical change is taken into account by a cost function with fixed inputs. At the stage of total energy demand this fixed input is the capital stock (where technology is embodied). At the stage of inter – fuel substitution the fixed inputs are non - fossil fuels (biomass, heat), which represent fossil – fuel saving or using technologies. Estimation results for the single equations and for the interfuel tanslog functions for the 13 activities are presented for Austria.

Key words: Translog functions, fuel substitution, embodied technical change.

JEL classification: Q41, C51, O33

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1. Introduction

Energy demand at a disaggregated level of economic activities and fuels is part of several large scale energy/economy models. One of the first models of this type which arised after the second oil price shock was the HERMES model for the European economies (Commission of the European Community (1993)). A recently constructed econometric large scale energy/economy/environment model is E3ME (Energy - Environment - Economy Model for Europe), which was a result of the modelling activities under the JOULE programm of the European Commission (s.: Barker, Gardiner, Dieppe (1996)). E3ME contains an energy submodel, where total energy input by different economic activities and the seperation of this total energy input in different fuels is described.

In energy modelling two important research directions can be seperated, one of which are the behaviour oriented (econometric) models of energy demand using flexible functional forms and paying less importance to technology. The other directions is characterized by engineering oriented models, where technologies are given and are chosen by restrictive behavioural functions (e.g. linear programming procedures). The practice of energy modelling tries to integrate these two directions and finds different ´ad hoc` solutions for this reconciliation. A well known example for this integration are the MIDAS and the PRIMES models both developed under the auspices of DG XII of EC (s.: Capros, Karadeloglou, et.al. (1996) and European Commission (1995)) .

In this study another disaggregated energy model, which could serve as the energy submodel of a large scale energy/economy model is developed. The ephasis of this model is on two important issues: (1) a consistent link between the two stages of total energy demand and inter

– fuel substitution and (2) an explicit treatment of technologies by considering embodied technical change at both stages of energy demand. The framework of the model is a nested demand structure of total energy demand and inter – fuel substitution with a clearly defined link between these two stages. This model structure is strongly inspired by the work of Harvey, Marshall (1991). Another feature is the introduction of embodied technical change at the two stages and combining it with the deterministic linear trend traditionally used for explaining technical change.

An important research line of the treatment of embodied technical change is the concept of a cost function with (short run) variable and fixed factors. There are several studies treating the capital stock as this fixed factor in a K,L,E,M cost function (Berndt, Hesse (1986), Morrison (1992)). An important contribution in the field of energy demand in this line is the study of Berndt, Kolstad, Lee (1993), which describes energy demand in a K,L,E,M function differentiating between embodied and un – embodied technical change.

This study combines the general model structure of Harvey, Marshall (1991) with the concept of fixed factors at the (first) stage of total energy demand as well as at the (second) stage of inter – fuel substitution. At the first stage of single equations for total energy demand the capital stock plays the role of the fixed factor. At the second stage of translog functions for fossil fuels demand the quantities of non – fossil fuels (biomass and heat) are the fixed factors. The specification of fixed factors in terms of quantities allows the derivation of shadow prices for these factors and their comparison with market prices. In simulations the costs of fossil fuel saving measures at the level of total energy efficiency and at the level of fuel substitution can be calculated.

2. Energy Demand and Embodied Technical Change

The final energy demand model constructed here is based on the combination of a translog cost function for fuel allocation with single equations for total energy demand (in energy units) by activities as lined out in the work of Harvey, Marshall (1991). The activity classification (12 industries and households) is an aggregate version of the 32 industries of the multisectoral model E3ME (for correspondence between the 32 industries of E3ME and the 12 activities see the Appendix).

In the model for total energy demand we assume, that firms in the different activities produce output Q with inputs of the variable factor energy (E) and of the fixed factor capital (K). These firms face a (short run) variable cost function, which depends on given factor prices (p_E as the price of energy), output level Q, capital stock K and the linear deterministic trend, t. Technical change is like in the work of Berndt, Kolstad, Lee (1993), specified by an embodied component represented by the capital stock, K, and an un – embodied component represented by the linear deterministic trend, t. At this level of total energy demand for a bundle of fuels total costs C can be split up in variable costs for the variable factor energy, EC , and fixed costs for the fixed factor capital with market price p_K .

(1) $EC = f(p_E, K, Q, t)$

(2) $C = f(p_E, K, Q, t) + p_K K$

As is well known, in a perfect factor market the condition must hold, that the market price of the fixed factor, p_K, equals the ´shadow price` derived from the variable cost function by

(- δ EC /δ K) . The ´shadow price` just expresses the willingness to pay for the fixed factor, given by the impact of the fixed factor quantity on variable costs.

$$(3)\ p_K = - \delta EC / \delta K$$

Assuming a flexible form for (1) without any a priori restrictions, one could specify a derived factor demand equation in terms of energy input coefficients:

$$(4)\ \log(EN/Q) = en\ (\log(k),\ \log(p_E),\ t,\ \Phi_E)$$

with $k = K/Q$ and Φ_E as a set of energy relevant variables (in this case log(DGD) ; DGD = degree days).

Capital stock is not as in the work of Berndt, Kolstad, Lee (1993) measured taking into account depreciation, but is simply approximated by cumulated investment:

$$(5)\ K_\tau = \sum_{t=0}^{\tau} I_t$$

In the case of the households sector the energy coefficient was derived by using disposable income as the output variable and as the energy relevant capital stock of housdeholds cumulated investment in dwellings is chosen.

3. Inter – Fuel Substitution and Embodied Technical Change

Total energy demand determined by (4) consists of a bundle of (short run) variable energy inputs, EN_v and a bundle of fixed energy inputs, EN_f . The emphasis of this paper is on fossil fuel use, so that variable energy input is the sum of the fossil fuel inputs of coal, derived oil, gas, electricity and fixed energy input is the sum of the non – fossil fuel inputs of biomsass and heat/steam. The idea behind this specification is that embodied technical change occurs by the introduction of certain technologies with a fixed non – fossil fuel input.

(6) $EN = EN_v + EN_f$

Total energy cost of (1) can now be further split up in variable energy costs EC_v for the variable energy inputs EN_v and fixed energy costs Z_f EN_f for the fixed energy inputs EN_f. Again the shadow price of the fixed input f ,Z_f , can be derived by ($- \delta EC_v / \delta EN_f$) . Note that the specification allows for more than one fixed input as in Berndt, Kolstad, Lee (1993).

(7) $EC = EC_v + \sum_f Z_f EN_f$

(8) $Z_f = - \delta EC_v / \delta EN_f$

The average (short run) variable energy costs AEC_v are a function of all input prices for the v variable factors P_v , of the ´quantity shares` of the fixed factors ($w_f = EN_f/EN_v$) and of the deterministic trend t for un – embodied technical change. Technical change is therefore the sum of the embodied component in w_f and of the un – embodied component, t.

(9) $AEC_v = EC_v/EN_v = g(P_v , w_f , t)$

For each of the 13 activities (12 industries plus households) AEC_v is described as a translog function with AEC_v as the aggregate price of the variable energy - bundle in the corresponding activity.

$$(10)\ \log AEC_v = a_0 + a_T t + 0,5\, a_{TT} t^2 + \sum_v a_v \log P_v + \sum_f a_f \log w_f + 0,5 \sum_v \sum_f \beta_{vf} (\log P_v)(\log w_f) + \sum_f \gamma_{tf} \log w_f\, t + \sum_v \gamma_{tv} \log P_v\, t$$

v = coal, derived oil, gas, electricity

f = biomass, steam/heat.

Applying Shephard's Lemma, the partial derivatives of this unit cost function yield the participations (S_i) of the different variable fuels in total unit cost of energy (s.: Berndt,Wood (1975) and Harvey, Marshall (1991)).

$$(11)\quad \frac{\delta \log AEC_v}{\delta \log P_i} = \frac{P_i\, EN_i}{EC_v} = S_i \qquad ; \quad i\ \varepsilon\ v$$

$$(12)\quad \frac{\delta \log AEC_v}{\delta \log P_i} = S_i = a_i + \sum_v \beta_{iv} (\log P_v) + \sum_f \beta_{if} (\log w_f) + \gamma_{ti}\, t \qquad ; \quad i\ \varepsilon\ v$$

The partial derivatives of (10) with respect to the fixed input quantities yield the well known shadow value equations (s.: Berndt, Hesse (1986) and Conrad, Seitz (1994)):

$$(13)\quad \frac{\delta \log AEC_v}{\delta \log (EN_k/EN_v)} = \frac{Z_k\, EN_k}{EC_v} = S_k \;; \qquad k \;\varepsilon\; f$$

$$(14)\quad \frac{\delta \log AEC_v}{\delta \log w_k} = S_k = a_k + \sum_f \beta_{kf}(\log w_f) + \sum_v \beta_{kv}(\log P_v) + \gamma_{tk}\, t \;; \quad k \;\varepsilon\; f$$

These equations are the special case of (8) for the translog function showing that the shadow price of the fixed factor is determined by the impact of the fixed factor input on variable costs. This impact can at the level of certain variable inputs be positive or negative. One could think of fossil fuels saving technologies as well as of joint technologies of biomass/fossil fuels or higher electricity input for using equipment with steam/heat input.

In studies where (10) is written not as the average cost function but as the total cost function (EC_v) like in Berndt, Hesse (1986) and Conrad, Seitz (1994), an output term (in this case EN_v) would be included on the right hand side. This would yield as an additional relationship the price equation as the partial derivative ($\delta \log EC_v$ / $\delta \log EN_v$) assuming that price = marginal cost as in Berndt, Hesse (1986) or allowing for a constant mark up on costs like in Conrad, Seitz (1994).

In this study we use the corresponding price (cost) index of the translog specification which - as Harvey, Marshall, (1991) point out - is the Divisia – price index :

$$(15)\quad \delta \log AEC_v = \sum_v S_v\, \delta \log P_v$$

One may note that this is equivalent to the assumption that the price equals marginal costs and simply describes the price of the bundle of variable energy input. From (4) we see that total energy demand depends on the energy price including the costs of the fixed factors, for which a market price can be observed. It may be seen as the specific feature of embodied technical change at the level of inter – fuel substitution, that the market price can be directly observed and has not to be estimated as in the case of private capital stock (s.: Berndt, Hesse (1986)) or is even unobservable as in the case of public infrastructure (s.: Conrad, Seitz (1994)).
An additional relationship in this model is the price equation for $p_E = EC/EN$. We assume, that this price of total energy inputs is set as a mark up on the average variable cost for fossil fuel input. This reflects the fact, that the prices of fossil fuels and non – fossil fuels are linked in a certain manner, which can be expressed by a fixed relationship of the movement of the total energy price and the price of the fossil energy bundle with the constant mark up μ.

(16) $p_E = EC/EN = (1 + \mu)\, AEC_v$

The usual accounting identity in a model with fixed inputs between output in current prices, variable costs and the quasi-rents of the fixed factors can in this context be written as:

(17) $Z_f\, EN_f = p_E\, EN - AEC_v\, EN_v$

The interpretation of Z_f is a ex post rate of return, as Berndt, Hesse (1986) have pointed out : „ ..the best firms can do for their shareholders in the short run given exogenous input prices, output demand .., and the fixed capital stock ..“ (p.967). It must be added that in the case where price $\neq$ marginal cost this also includes a certain price setting behaviour according to the market form represented here in (16). This means that the ex post rate of return for non – fossil fuel input also depends on the common movements of fossil and non – fossil fuel prices. In a perfect factor market one would expect, that the market price for a fixed factor P_f equals the ex post rate of return ($P_f = - Z_f$). If as in the model used here the market prices are directly observable, one can test this hypothesis and investigate the deviations of the two price measures.

The model can be set up then by estimation of (4), (12), (14) and (16), where (12) and (14) are jointly estimated in a system. The restrictions of the translog functions ((12) ,(14)) are:

$$\sum_i a_i = 1 \; ; \; \sum_i \beta_{ik} = 0 \; ; \; \sum_i \gamma_i = 0 \qquad \text{additivity} \; ; \quad i,k \; \varepsilon \; v \cup f$$

$$\beta_{ik} = \beta_{ki} \qquad \text{symmetry} \; ; \quad i,k \; \varepsilon \; v \cup f$$

$$\sum_k \beta_{ik} = 0 \qquad \text{homogenity} \; ; \quad i,k \; \varepsilon \; v \cup f$$

Elasticities of substitution and cross and own price elasticities are in the translog function given starting from the AES (Allens Elasticities of Substitution). The general formulation of the AES is:

$$(18) \quad \sigma_{ik} = \frac{C\,(\delta^2 C / \delta P_i \, \delta P_k)}{(\delta C / \delta P_i)\,(\delta C / \delta P_k)} \qquad \text{when } i \neq k \;\; \varepsilon \;\; v$$

$$(19)\quad \sigma_{ii} = \frac{C\,(\delta^2 C / \delta P_i^2)}{(\delta C / \delta P_i)\,(\delta C / \delta P_i)} \qquad \text{when } i = k \;\; \varepsilon \;\; v$$

This gives:

$$(20)\ \sigma_{ik} = (\beta_{ik} + S_i S_k)/(S_i S_k) \qquad \text{when } i \neq k \;\; \varepsilon \;\; v$$

$$(21)\ \sigma_{ii} = (\beta_{ii} + S_i^2 - S_i)/ S_i^2 \qquad \text{when } i = k \;\; \varepsilon \;\; v$$

and for cross and own price elasticities:

$$(22)\quad \varepsilon_{ik} = \sigma_{ik} S_k$$

$$(23)\quad \varepsilon_{ii} = \sigma_{ii} S_i$$

Taking into account, that $\delta EN_i / \delta P_i = \delta^2 C / \delta P_i^2$ and $EN_i = \delta C / \delta P_i$ Atkinson, Halvorsen (1976) have shown, that (23) is equivalent to the general formulation of the own price elasticity:

$$(24)\ \varepsilon_{ii} = \frac{\delta EN_i}{\delta P_i} \; \frac{P_i}{EN_i} \qquad ; \;\; i \;\; \varepsilon \;\; v$$

A general formulation of the „cross quantitiy elasticities“ of the quantity of a variable factor i with respect to the fixed factor quantity share, w_f in this model is:

$$(25)\ \varepsilon_{ii} = \frac{\delta EN_i}{\delta w_f} \frac{w_f}{EN_i} \quad ;\ i\ \varepsilon\ v$$

As (24) is identical to (23) the „cross quantitiy elasticities“ can also be derived in analogy by starting from:

$$(26)\quad \sigma_{if} = \frac{C\,(\delta^2 C / \delta P_i\, \delta w_f)}{(\delta C / \delta P_i)\,(\delta C / \delta w_f)} \qquad \text{when } i\ \varepsilon\ v$$

This yields terms for the „cross quantitiy elasticities“ similar to the AES and to the cross price elasticities:

$$(27)\quad \sigma_{if} = (\beta_{if} + S_i S_f)/(S_i S_f) \qquad \text{when } i\ \varepsilon\ v$$

$$(28)\quad \varepsilon_{if} = \sigma_{if} S_f$$

The model can be used for forecasts or simulations combining the different equation sets. In a first step when Q, K , Φ_E , w_f and P_i are given the shares S_i, the average variable cost AEC_v , the energy bundle price p_E and the energy input coefficients EN/Q can be calculated with the use of (4), (12), (15) and (16). Then variable and fixed energy input must be solved simultaneously in the following system:

(29) $EN_f = w_f EN_v$

(30) $EN_v = (EN/Q)\ Q - EN_f$

(31) $EC_v = AEC_v EN_v$

(32) $EN_i = (S_i EC_v)/ P_i \quad ; \; i \ \varepsilon \ v$

The model solves for quantities of fixed inputs EN_f as the product of their (exogenous) quantity shares and total variable energy input, which is also influenced by fuel prices and the total energy price. The shadow value equations (14) can then be used to calculate shadow prices, Z_f of the fixed inputs:

(33) $Z_k = (S_k EC_v)/ EN_k \quad ; \; k \ \varepsilon \ f$

4. Estimation Results

This section deals with the estimation of the share equation system ((12), the shadow value equations (14) and the energy input equations (4). The price equations (16) have also been estimated, but the results are of minor interest. All estimations have been undertaken for the following activities, which are defined by the classification structure of E3ME (see Appendix):

1 Iron & Steel, Non-ferrous Metals
2 Chemicals
3 Mineral Products
4 Food, Drink & Tobacco
5 Textiles, Clothing & Footwear
6 Paper & Printing
7 Engineering etc.
8 Other Industry
9 Inland Transport
10 Air Transport
11 Inland Navigation
12 Other Final Use
13 Households

The translog function describes the system of the share equations (12) and the additivity restriction must hold in this system. Some parameters, which appear in (12) are also part of the shadow value equations (14) given by the symmetry restriction. The equation set (12) which contains the equations for the variable (v) inputs coal, derived oil, gas and electricity is therefore estimated jointly in a system with the equation set (14) which contains the equations for the fixed (f) inputs biomass and heat/steam. In the literature one finds different approaches concerning the joint estimation of the share equations and the cost function (10). There is one important point in practice concerning the availability of data to specifiy (14). What is needed for the specification of the dependent variable $\frac{Z_k \, EN_k}{EC_v} = S_k$ are observable data for Z_k.

In the case of the Conrad, Seitz (1994) study, where the fixed factor is public infrastructure and the market price is not available the cost function has to be estimated together with the share equation system in order to derive all necessary parameters. The shadow price of the fixed factor can then be calculated from the paramter values. Berndt, Hesse (1986) are discussing the option to take some measure for the market price of the fixed factor as a starting point to specify the dependent variable of the shadow value equation. This research line is followed here, as the market price for the fixed factors is directly observable without computations like in the case of the private capital stock. One additional result of the study is then, that the residual of the shadow value equation determines the differential between the shadow price and the market price of the fixed factors.

The underlying data are time series from 1976 to 1995, based on the national energy balances of Austria and data about monetary expenditure for energy by activities. A full cross sectional data set of money expenditure for energy from official statistics was available for some base years (input – output years, full census of the Austrian economy): 1976, 1983, 1985, 1988. Between these base years data to build price indicators could be taken from industrial statistics for energy input in money terms and in quantities and from the consumer price index for energy commodities. The further was applied for activities 1 to 8 and the latter for the other activities in order to interpolate between these years in a smoothed interpolation procedure without structural breaks around the base years. By this method a full data set for money expenditure for energy in the Austrian economy could be constructed for 1976 – 95. An important feature of this data set is, that it incorporates price differentiation for the same fuel in different activities and takes changing trends in this price differentiation into account. The share equation system has been estimated with SURE applying homogenity and symmetry restrictions. Homogenity implies that $1 - \sum_{k-1} \beta_{i,k-1} = \beta_k$. This restriction therefore can be easily applied by omitting the k equation. The system estimated therefore can be described by:

$$(34)\quad S_i = a_i + \sum_{k-1} \beta_{i,k-1} (\log (X_{k-1}/X_k)) + \gamma_i t + e_{it} \qquad \text{with} \quad i = 1 \ldots k - 1$$

where X represents exogenous factor prices or quantity shares of fixed factors and e is a pertubatory term.

The estimation results for the translog model of the Austrian final energy demand are shown in Table 1 and 2. It proofed inefficient to estimate the system for the two transport activities 9 and 10 and it was decided to model the energy demand in these sectors in a different way. Table 1 shows the parameters for the variable factors coal (KO), derived oil (DO), gas (NG) and electricity (EL). These parameters only appear in the share equation system (12). The omitted equation is the share equation for electricity. Parameters for this energy type have been derived by homogenity restriction. In activity 1 (iron & steel) the equation for gas (which includes coke oven and blast furnace gas) was chosen to be the omitted equation. As is well known, the results in the translog function are independent of which share equation is omitted. Table 2 shows the parameters β_{vf} which appear in the share equation system as the parameters for embodied technical change as well as in the shadow value equations and the parameters for un- embodied technical change, γ_{vt}. The results Berndt, Kolstad, Lee (1993) found in a K,L,E,M framework are reproduced here at the level of inter – fuel substitution namely that embodied and un – embodied technical change play a role in energy demand. A negative parameter value for β_{vf} means that the quantity input of fuel f is fuel saving for v and a positive means that it is fuel using.

With the parameters estimated the elasticities can be calculated according to (22), (23) and (28). In Table 3 the own price elasticities are shown. Usually these elasticities are calculated taking the average shares S_i over the sample period. In this study the elasticities have been calculated for the whole sample and then the mean was taken. In some cases, where no negative value for the mean of own price elasticity could be found, a negative maximum value turned out to have the expected sign (in 1 and in 12 for gas). In a number of activities (4, 5, 6, 7, 8, 12) it is not possible to derive a significantly different from zero own price elasticity for electricity. Especially the results for activity 12 (other final use), which contains the whole service sector were rather unsatisfying. It seems that further research to explain energy demand in this sector has to be undertaken. Robust results for own price elasticities were achieved for the household sector.

The general result for the „cross quantity elasticities“ for biomass and heat in Table 4 is that these fuels have fossil fuel saving as well as fossil fuel using impacts. Of the 72 listed elasticities in Table 4 about ten negative elasticities for coal and gas can be found, but only five for derived oil. It seems that heat in the household sector is an important technology for energy saving of derived oil input.

The results for the energy input equations are shown in Table 5. Except the activities 1,5 and 8 the capital stock as a measure of embodied technical change has an important impact on energy efficiency. The results in none of the sectors with embodied technical change could be improved by including the linear deterministic trend in the equation. So in general the specification chosen in this study allows to detect important impacts of embodied technical change on energy efficiency and fossil fuel saving impacts of non – fossil fuel technologies. On the other hand for some fossil fuels also energy using impacts of embodied technical change can be found.

The estimation results can as in Conrad, Seitz (1994) be used to calculate shadow prices for the fixed factor according to (33). In this study these calculated shadow prices can be compared to the actual market price, which were used to compute the dependent variables for estimating the shadow value equations (14). The comparison in Table 6 is limited to some activities, where the fixed inputs play an important role. It is interesting to see, that for biomass over the whole sample (1976 – 95) the actual market prices have been higher than the shadow prices, especially in paper & printing. This activity has totally changed the production process during this period and has continously increased the share of biomass in total energy use. For steam the market prices have been slightly below the shadow prices for 12 and for households over the whole sample.

6. Summary and Conclusion

The purpose of this paper is to integrate embodied technical change at the level of total demand and of inter – fuel substitution. Another important feature is a consistent link between these two demand stages. The approach of a cost function with variable and fixed factors showed that the capital stock at the level of total energy demand is energy saving and the non – fossil fuels biomass and heat are fossil fuel saving as well as using at the level of inter – fuel substitution. Shadow prices for biomass and heat were calculated and compared to actual market prices. It was shown, that market prices are above shadow prices for biomass and are below for heat. Obviously there are important barriers for the introduction of heat technologies. Fossil fuel prices and the quantity shares of biomass and heat are exogenous, what offers a wide range to simulate the impact of energy policy measures on energy demand and costs .

References

Atkinson,S. E., Halvorsen, R., (1976), Interfuel Substitution in Steam Electric Power Generation, *Journal of Political Economy*, 84, 959 - 978

Barker,T., Gardiner, B., Dieppe, A. (1996) *E3ME - An Energy - Environment - Economy Model for Europe, Users´ Manual* (Cambridge Econometrics)

Berndt, E. R., Wood, D. O. (1975), Technology, Prices and the Derived Demand for Energy, *The Review of Economics and Statistics*, 57, 259 - 268

Berndt, E. R., Hesse, D. (1986), Measuring and Assessing Capacity Utilization in the Manufacturing Sectors of Nine OECD Countries, *European Economic Review*, 30, 961 - 989

Berndt, E. R., Kolstad, Ch., Lee , J. - K. (1993), Measuring the Energy Efficiency and Produtivity Impacts of Embodied Technical Change, *The Energy Journal*, 14, 33 - 55

Capros,P., Karadeloglou,P., Mantzos,L., Mentzas,G. (1996), The Energy Model MIDAS, in: Lesourd, J.-B., Percebois, J., Valette, F., (eds.), *Models for Energy Policy*, London (Routledge) , 41 - 64

Commission of the European Communities, eds., (1993), *HERMES: Harmonised Econometric Research for Modelling Economic Systems*, Amsterdam (North-Holland)

Conrad,K., Seitz,H. (1994), The Economic Benefits of Public Infrastructure, *Applied Economics*, 26, 303 - 311

European Commission, (1995) Directorate-General XII, *The Primes Project*, Brussels , EUR 16713 EN

Harvey, A. C., Marshall, P. (1991), Inter-Fuel Substitution, Technical Change and the Demand for Energy in the UK Economy, *Applied Economics*, 23, 1077 - 1086

Lesourd, J.-B., Percebois, J., Valette, F. (eds.) (1996), *Models for Energy Policy*, London (Routledge)

Morrison, C.J. (1990), Decisions of Firms and Productivity Growth with Fixed Input Constraints on : An Empirical Comparison of U.S. and Japanese Manufacturing, in: C. Hulten, (ed.), *Productivity Growth in Japan and the United States*, Chicago:University of Chicago Press, 135 - 172

Appendix

The 12 industries plus households of the energy submodel presented here can be seen as an aggregated version of the 17 industries of the energy submodel in E3ME . The correspondence between these 17 industries and the 32 industries is:

	17, E3ME	32, E3ME
1 Iron & Steel, Non-ferrous Metals	2+3	8
2 Chemicals	4	10
3 Mineral Products	5 + 6	9
4 Food, Drink & Tobacco	7	16
5 Tex., Cloth. & Footw.	8	17
6 Paper & Printing	9	18
7 Engineering etc	10	12 to 15
8 Other Industry	11	11, 19 to 21
9 Inland Transport	12+13	25
10 Air Transport	14	26
11 Inland Navigation	15	27
12 Other Final Use	17	1,7,22 to 24, 28 to 32
13 Households	16	