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Modelling Energy Demand in Germany

A Cointegration Approach

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Abstract:
Economists frequently argue that environmental taxes are suitable for the purpose of fulfilling the commitments of greenhouse gas emissions specified in the Kyoto Protocol. The magnitude of such taxes does however depend in part on the price sensitivity of energy demand. Hence, the fulfilment of the Kyoto Protocol requires updated knowledge of the energy demand structure in each Annex B country. This paper utilises Engle and Grangers (1987) cointegration methodology as a basis for modelling energy demand in Germany. Using annual data over the period 1960-1993, we obtain a cointegrating vector between energy demand, output and prices in each energy using sector. We find considerable variation in the estimated energy demand elasticities across sectors. The average long run elasticities with respect to output and prices are 0.75 and −0.3, respectively. As a consequence, we may argue that CO_2 emissions from Germany are not greatly affected by energy price changes through environmental tax reforms.

Keywords: Energy demand, cointegration, equilibrium correction model, elasticities.

JEL classification: C22, Q41.

Acknowledgement: Statistics Norway has in co-operation with Cambridge Econometrics, England, developed an energy demand system, both aggregated and disaggregated, for several Western European countries as part of an integrated Energy-Environment-Economy model for Europe (abbreviated E3ME). This paper is an outcome of that project and intends to document some of the work that was undertaken in 1997-98, while the author was engaged in the development of the E3ME-model. The author is indebted to Ådne Cappelen and Bjørn Naug for useful discussions and comments on an earlier draft, and to seminar participants for feedback received at Cambridge Econometrics. The data used in the analyses was kindly provided by Cambridge Econometrics. The econometrics was conducted using PcGive Professional Version 8.0 [cf. Doornik and Hendry (1994)]. Financial support by the Commission of the European Communities, Directorate-General XII for Science, Research and Development, under the EC Non-Nuclear Energy Programme: JOULE-II, is gratefully acknowledged.

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1. Introduction

Following the oil price shocks in the 1970s and 1980s and the increasing importance of energy in national economies, economists have devoted considerable efforts to the study of *aggregate* energy demand. Econometric studies include Beenstock and Willocks (1981), Kouris (1981, 1983a.b), Nguyen (1984), Bopp (1984), Prosser (1985), Ramain (1986), Hunt and Manning (1989), Welsch (1989), Brennand and Walker (1990), Paga and Brennand (1990), Bentzen and Engsted (1993) and Jones (1994) among others. In most of these studies, the primary objective has been to obtain estimates of price and income elasticities in a given country or across countries. The evidence shows long run income elasticities about unity, and the price elasticity is typically found to be rather small.

However, more research seems needed in this field, as differences in the definition of aggregate energy demand, the time period studied and the choice of dynamic specification are among the causes for the wide variation in the estimated elasticities. In this respect, it is surprising that recent studies are quite reluctant to apply Engle and Grangers (1987) cointegration methodology.[1] Moreover, few studies examine energy consumption at a disaggregated level of the economy.[2] Normally, as pointed out by Barker and Pesaran (1990), aggregate modelling in general involves a loss of information and also runs the risk of aggregation bias in the estimated parameters. Additionally, disaggregated energy demand analyses seem called for if the Kyoto Protocol is to be successfully fulfilled. Why? Economists frequently argue that environmental taxes are suitable for the purpose of fulfilling the commitments of greenhouse gas emissions specified in the Protocol. The magnitude of such taxes does however depend in part on the price sensitivity of energy demand. Hence, the fulfilment of the Kyoto Protocol requires updated knowledge of the energy demand structure in each Annex B country at a disaggregated level.

The aim of this paper is to present the modelling and estimation of energy demand for each energy using sector in Germany. As such, this paper adds to the rather limited empirical literature of disaggregated energy demand studies. Germany is chosen as this country plays an important role in the dimension of energy consumption and the associated CO_2 emissions in Western Europe. We apply the concept of cointegration and EqCM modelling in order to estimate both short and long run energy demand elasticities. Using annual data over the period 1960-1993, we obtain a cointegrating vector between energy consumption, output and prices in most of the energy using sector. We find considerable variation in the estimated energy demand elasticities across sectors. This finding may be explained by the characteristics of each energy using sector with respect to its flexibility or lack of flexibility to change production and consumption behaviour over time. The average long run output and price elasticities are estimated to 0.75 and –0.3, respectively. As a consequence, we may argue that CO_2 emissions from Germany are not greatly affected by energy price changes through environmental taxes.

The rest of the paper is organised as follows: Section 2 outlines the economic background of the energy demand modelling and Section 3 briefly describes the data. Section 4 contains a description of the methodology applied and Section 5 presents estimation results. Section 6 concludes.

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[1] Some studies have estimated energy demand schedules using cointegration techniques and equilibrium correction models (EqCM) [see e.g. Bentzen and Engsted (1993) and Samimi (1995)].

[2] Exceptions include the contributions by Walker and Wirl (1993) and Samimi (1995). The former studies energy demand in road transport in France, Germany and Italy, while the latter studies road transport energy demand in Australia.

2. Economic Background

The modelling of energy demand is based on work by Hunt and Manning (1989) and Barker *et al.* (1995). Hence, the energy demand equation to be estimated generally reads as

$$(1) \qquad E_{it} = f(Y_{it}, P_{it}, T),\ i=1,..,17,$$

where E_{it} is aggregate energy demand, Y_{it} is an activity measure (usually real income or output), P_{it} is real energy price and T is a deterministic and linear time trend proxying technological progress. The subscript i denotes the energy using sector i, while t denotes time.

In the empirical analysis, we assume that (1) can be expressed by the following log-linear equation:

$$(2) \qquad e_{it} = \ln(\mu) + \alpha \cdot y_{it} + \beta \cdot p_{it} + \delta T + \varepsilon_{it},$$

where logarithms of variables are denoted by lower case letters. Noticeably, (2) is augmented with an error term ε_{it}. We note that the long run elasticities of energy demand with respect to the activity measure and the energy price are α and β, each of which is hypothesised to be greater than or equal to zero and less than or equal to zero, respectively. The coefficient δ is hypothesised to be less than or equal to zero under the assumption that available energy saving techniques become more efficient over time. No other a priori restrictions are imposed. It is however assumed a priori that the numerical value of the long run activity elasticity is greater in absolute terms than the long run price elasticity. This assumption accords with the conventional view about the relative magnitude of the energy demand elasticities.

The logarithmic formulation in (2) corresponds with the traditional energy demand modelling [see for instance, Kouris (1981), Welsch (1989) and Jones (1994)]. This formulation implicitly assumes a stable long run demand function, which implies the existence of a unique equilibrium demand for any given price level, *ceteris paribus*. Thus, (2) assumes perfect price reversibility so that the energy demand effects of any price change will be totally reversed as price returns to its initial level (i.e., symmetric energy demand responses). Following the oil price fall of 1986, there has been much debate concerning the possible asymmetric nature of the energy markets. Some few recent econometric studies have examined this hypothesis [see for instance, Gately (1993) and Dargay and Gately (1994)]. These studies conclude that the OECD non-transport oil demand response to the price cuts of the 1980s has been significantly smaller than the response to the price increases of the 1970s. The conclusion regarding the effect on demand of the price recovery in the 1990s relative to the price increases of the 1970s are however uncertain. Some analysts [e.g. Hogan (1993)] are reluctant to abandon the conventional demand specification as they argue that more extensive research about the hypothesis are needed before any final conclusion can be drawn. Despite the inability of (2) to incorporate any possible asymmetric price effects, we decided to follow the argument made by these analysts. Since (2) is interpreted as a long run demand function, it will serve as a foundation for the cointegration analysis below. Owing to adjustment costs and incomplete information energy demand may very well in the short run deviate from long run equilibrium. To account for such possible behaviour of the energy users, an empirical version of (2) ought to be specified dynamically.

Apart from any problems caused by aggregation across various forms of fuel types or the possibility of asymmetric price effects in the energy markets, the task of estimating the energy demand elasticities may be further complicated by the presence of technological progress. While an increase in the current price of energy will lead to reduced energy consumption, that price increase, if sustained, can also provide the necessary incentive for energy using sectors to find new ways to slowly increase energy's productivity over time. As noted by Kouris (1983a), there may be different factors that contribute to technical progress other than such price-driven energy substitution. For instance, environmental regulations, energy efficiency standards and the substitution of labour, capital or raw materials inputs for energy inputs could also lead to reduced energy use. However, as pointed out by Jones (1994), researchers have not reached a consensus on how to account for technical progress when modelling energy demand. Since the level of technology is not directly observable some include a time trend or other proxies for technological progress, while others omit the trend in a dynamic model.

While recognising these possible caveats when accounting for technological progress, a technological progress variable defined as R&D-enhanced accumulated investment was tried instead of the trend variable.[3] However, preliminary investigations revealed that this variable in most cases did not provide energy demand elasticities with hypothesised signs and reasonable magnitudes. Hence, we decided to rely on Jones' (1994) findings that including a time trend improves the model's fit and renders more reliable long run price elasticities (without affecting the other demand elasticities).[4]

3. The Data

The empirical analysis uses annual data that covers the period 1960-1993. This sample period was selected because it constitutes the longest possible consistent series of directly comparable, country specific final consumption and energy price data that are available. Data on consumption and prices prior to 1960 are much harder to obtain and generally considered to be less reliable. The data are mainly taken from the Eurostat's Cronos database and from their current publications of energy statistics. Detailed data definitions and sources are provided in Barker *et al.* (1998). Below, we content ourselves to a brief description of the data.

The following energy using sectors in Germany are modelled:

- Power Generation
- Iron and Steel
- Non-Ferrous Metals
- Chemicals
- Mineral Products
- Ore-extraction
- Food, Drink and Tobacco
- Textiles, Clothes and Footwear
- Paper and Printing
- Engineering
- Other industry
- Rail Transport
- Road Transport
- Air Transport
- Inland Navigation
- Households
- Other Final Use

We define energy demand (*E*) in each energy using sector as an aggregate constituting eleven different fuel types. The main fuel types are heavy fuel oil, natural gas, coal and electricity in most cases. *E* is measured in thousand tonnes of oil equivalents. The activity measure (*Y*) is defined as gross output for most of the energy using sectors, measured in million of ecu at 1985 constant prices. We note that road transport energy demand is a function of GDP and total imports, while households energy demand is a function of total consumers' expenditure. The energy price (*P*) is an average energy price faced by the energy using sector, measured in ecu per thousand tonnes of oil equivalents. This price is made real by deflating it with the overall price level in the German economy (*CPI*).

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[3] See Barker *et al.* (1998) for a description of the constructed R&D-enhanced accumulated investment variable.

[4] Jones' empirical analysis was based on annual observations on aggregate energy demand, real energy prices and the level of real economic activity for Canada, France, Germany (West), Italy, Japan, the UK and the USA from 1960 to 1990.

An informal inspection of the data series indicates that both *Y* and *E* tend to increase over the sample period, while *P* tends to fall. Most of the series appear to be I(1) according to Augmented Dickey-Fuller tests.[5] We thus regard *E,Y* and *P* to be I(1), i.e., they contain a unit root in levels and need to be differenced ones in order to become stationary. According to Engle and Grangers' (1987) theory of cointegration, this treatment implies that the linear combination of the variables given in (2) may well be a stationary I(0)–process, so that a cointegration relationship exists.[6] An important implication of such a result is that cointegration rationalises the use of EqCM models, and thus the possibility of estimating both short and long run energy demand elasticities. This is pursued in Section 5.

4. Empirical Methodology

Econometric techniques that are widely used when modelling both short and long term relationships include bivariate cointegration methods, proposed by Engle and Granger (1987) and Kremers *et al.* (1992), and the multivariate cointegration method developed by Johansen (1988, 1991). The former approaches are only valid if the explanatory variables are weakly exogenous for all parameters of interest [cf. Engle *et al.* (1983) and Urbain (1992)]. Thus, an EqCM model that is commenced from a single equation analysis in cases where weak exogeneity is not met will in general lead to invalid inferences. The Johansen method of cointegration overcomes these difficulties. However, this method is based upon VAR modelling, which in practice requires a relatively long sample period in each case. Given a sample of 34 observations and three variables, the Johansen method seems difficult to employ without losing too many degrees of freedom. For this reason, the empirical analysis of energy demand relies on the single equation approach. In so doing, we implicitly assume that *Y* and *P* are weakly exogenous for all parameters of interest, noting that some caveats may apply.

Below, we briefly outline the analytical relationships between autoregressive distributed lag models (ADL) and EqCM models in the context of energy demand modelling. Extensive discussions of these models on general terms appear in Pagan and Sargan (1984) and Hendry (1995) among others.

Our modelling strategy in the search for parsimonious energy demand models, is that of the *general to specific approach* advocated by Davidson *et al.* (1978). With annual data, a second-order ADL model in *E*, *Y* and *P* seems appropriate as the most general model. This model is modified in one way in that a dummy *D* is included to account for any outliers in the data that may arise from economic or political shocks. While the dummy variable may capture economically and statistically important behaviour in energy demand and its determinants, the effects from this variable are viewed as short run and are not included in the cointegration relationships. Hence, the second-order ADL of energy demand generally reads as follows (subscript *i* is omitted for sake of convenience):

$$(3) \qquad e_t = \alpha_0 + \sum_{i=1}^{2} \alpha_{1i} e_{t-i} + \sum_{i=0}^{2} \alpha_{2i} y_{t-i} + \sum_{i=0}^{2} \alpha_{3i} p_{t-i} + \alpha_4 T + \alpha_5 D_t + \varepsilon_t ,$$

where ε_t is the error term assumed to be white noise. Equation (3) may be reparameterised without loss of generality as an EqCM model by adding and subtracting lags of the variables:

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[5] The results from these tests are not reported, but are available upon request.

[6] Formally, a vector x_t containing a number of variables is said to be cointegrated of order d, b[CI(d,b)], if each of the variables are integrated of order d and there exists a matrix β such that $z_t = \beta' x_t$ is integrated of order d-b, b>0 [see Engle and Granger (1987)].

$$(4)\quad \begin{aligned}\Delta e_t &= \alpha_0 + \beta_{11}\Delta e_{t-1} + \sum_{i=0}^{1}\beta_{2i}\Delta y_{t-i} + \sum_{i=0}^{1}\beta_{3i}\Delta p_{t-i} \\ &+ \phi_1 e_{t-1} + \phi_2 y_{t-1} + \phi_3 p_{t-1} + \alpha_4 T + \alpha_5 D_t + \varepsilon_t,\end{aligned}$$

where Δ is the difference operator. With minor algebraic manipulation, (4) may be rewritten so as to incorporate the long run solution in (2) directly. Hence, we obtain the following EqCM model:

$$(5)\quad \begin{aligned}\Delta e_t &= \alpha_0 + \beta_{11}\Delta e_{t-1} + \sum_{i=0}^{1}\beta_{2i}\Delta y_{t-i} + \sum_{i=0}^{1}\beta_{3i}\Delta p_{t-i} \\ &+ \phi_1 (e - \alpha\cdot y - \beta\cdot p - \delta\cdot T)_{t-1} + \alpha_5 D_t + \varepsilon_t.\end{aligned}$$

Specifically, ϕ_1 is the adjustment coefficient in the case of disequilibrium in the previous period, $(e - \alpha y - \beta p - \delta T)_{t-1}$. The coefficients α, β and δ correspond to $-\phi_2/\ \phi_1$, $-\phi_3/\ \phi_1$ and $-\alpha_4/\phi_1$, which are the long run elasticities in (2), respectively. Under a static equilibrium, all growth rates, the dummy variable and the equilibrium correction term are zero in (4), and time subscripts can be ignored. That leaves (4) with the constant α_0, the trend variable and the levels of e, y and p. Moving e to the left hand side and renormalising, (4) solves for (2), and reads as:

$$(6)\quad e^s = -(\alpha_0/\phi_1) - (\phi_2/\phi_1)y - (\phi_3/\phi_1)p - (\alpha_4/\phi_1)T.$$

The superscript s in e^s indicates that (6) is the static equilibrium. The constant term $-\alpha_0/\phi_1$ in (6) is equivalent to $\ln(\mu)$ in (2). Thus, the EqCM model in (4) solves for the long-run solution (2) when evaluated under the static equilibrium assumption associated with (2). Equation (4) and (5) are general models in the sense that they contain both levels and first differences of the variables in question. As such, both short and long run elasticities of energy demand with respect to the activity measure and the energy price are possible to estimate simultaneously.

The empirical modelling of energy demand is based on estimations of equations (3)-(6) by Ordinary Least Squares (OLS).[7] This approach has some distinct advantages over the original Engle and Granger (1987) approach. First, the long run solution obtained in the first stage of the Engle and Granger procedure is known to have invalid standard errors due to lack of dynamics in the static levels regression. This potential problem may be overcome through the use of the ADL model in (3) [cf. Phillips and Loretan (1991)]. Second, Kremers *et al.* (1992) shows that the Dickey-Fuller unit-root test applied to the residuals from the first stage of the procedure in many situations has low power relative to a cointegration test which is based on inference about the coefficient on the equilibrium-correction term in the corresponding dynamic model. By using the equilibrium correction based procedure to (5), the cointegration test suggested by Kremers *et al.* (1992) may be carried out directly.

Kremers' et al. proposed cointegration test involves testing the null hypothesis that $\phi_1 = 0$ against the alternative that $\phi_1 < 0$. The critical values that should be used in order to make safe inference in the test are those from the Dickey-Fuller distribution [cf. MacKinnon (1991)] since $(e - \alpha y - \beta p - \delta T) \sim I(1)$ under the null hypothesis, and the estimate of ϕ_1 is thus not *t*–distributed. As previously noted, there is one potential caveat associated with this test procedure. The test is only valid when y_t and p_t are weakly exogenous for the parameters ϕ_1, α

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[7] We recognise that some simultaneity problems may arise by using OLS. That is, if $COV(\Delta y_t, \varepsilon_t) \neq 0$, then the short run parameters in (4) and (5) will be inconsistently estimated by OLS. However, preliminary investigations showed that estimations of (4) and (5) with lagged values of Δy_t as instruments for Δy_t itself more or less produced identical estimates as OLS. We thus assume that any simultaneity bias is negligible.

and β. Otherwise, one should apply the Johansen (1988, 1991) method to avoid the risk of losing efficiency. This method is however beyond the scope of the present paper.

5. Estimation Results

In this section we present estimation results for energy demand in Germany. First, a derived long run solution is derived for each energy using sector from an estimated ADL model in E, Y and P. Second, EqCM models are derived from these ADL models. Throughout the presentation of the different models the constant term and the dummy D are omitted for simplicity of exposition.[8] Usual misspecification tests are also carried out together with the estimations of the different models.

The starting point for the energy modelling was a specification search among potential ADL models, a specification search based on the following *general to specific approach*: The most general ADL model in (3) was first estimated for each energy using sector. Then, insignificant coefficients were restricted to zero and the resulting simplified model was estimated. This latter stage of the modelling was repeated until a parsimonious ADL model was obtained. Noticeably, the simplification of the general model was also influenced by the a priori assumption that Y is the most important variable in explaining energy demand, whereas P is the least important.

Table 1 presents the estimated ADL model for 12 energy using sectors out of 17 in total. No ADL model, and hence no long run solution and corresponding EqCM models, are reported for the users Ore-extraction, Food, Drink and Tobacco , Textile, Clothes and Footwear, Road Transport and Inland Navigation, as the estimation results tended to give implausible long run elasticities. One possible explanation for the estimation difficulties with these users may be supply side effects and institutional circumstances that are not picked up by Y and P.[9] Moreover, all price parameters for the users Power Generation and Engineering are forced to zero as the estimation results either gave highly insignificant long run price elasticities or price elasticities contradicting the hypothesised sign. The models reported in Table 1 are all simplified versions of the general ADL model, and are parsimonious in the sense that they represent the most satisfactory models with respect to achieving as economically interpretable and statistically acceptable long run solutions and EqCM models as possible. Even with restrictions imposed on the second order ADL model, it is evident that some of the individual coefficients in most of the models are imprecisely estimated. However, the coefficients in the ADL models are of little interests in themselves. The corresponding long run solutions and EqCM models are of greater interest, which we focus on below.

Table 2 reports economic and statistical properties of the static long run solutions derived from the ADL models. These solutions correspond to (2) and (6). Even though the constant term has no particular economic interpretation as far as energy demand is concerned, it is included in the long run solutions for econometric purposes.[10] Generally speaking, the estimated long run elasticities are fairly plausible. For instance, all estimated elasticities have their hypothesised sign. Numerically, the coefficients of the activity variable are larger than that on the price

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[8] Generally speaking, separate dummy variables were included for the oil price shocks in 1974, 1986 and 1991. These dummies proved to be significant as well as necessary variables in the majority of the regression models to render white noise properties in the residuals.

[9] Together these energy users accounted for around 16 per cent of total energy use in Germany in 1993.

[10] The numerical value of the constant term is dependent on the scale of the variables in the econometric specification, and hence included to avoid any possible misspecifications. For example, suppose the long run solution of aggregate energy demand is $\ln(E)=\alpha\ln(Y)$ derived from estimation of an ADL model without a constant. If the scale of Y is changed to $Y'=Y/100$, then the new long run solution becomes $\ln(E)=\alpha\ln100+\alpha\ln(Y')$.

variable. This accords with our a priori view about the relative magnitude of the elasticities. Specifically, the long run output elasticity ranges from +0.31 (Iron & Steel) to +1.69 (Air transport), while the long run price elasticity ranges from –0.05 (Mineral Products) to –0.64 (Paper & Printing). The average long run output and price elasticity are thus estimated to around +0.75 and –0.3, respectively. The latter elasticity indicates that energy demand presumably is quite inelastic with respect to price changes. As a consequence, we may argue that CO_2 emissions from Germany are not greatly affected by energy price changes through environmental tax reforms. The coefficients of the technological progress variable are perhaps a little more controversial. Among those reported, the semielasticity of –4.9 (–0.049x100) for Air transport represents the largest estimated coefficient, and indicates that energy demand on average decreases by 4.9 per cent annually, *ceteris paribus*. The estimated semielasticity for the other energy using sectors ranges from –2.4 (Iron & Steel) to –3.9 (Other Industry). In comparison, the technical progress in more aggregate studies also various considerably. For instance, the annual rate of technical progress is estimated to be only 1.5 per cent in Jones' (1994), substantially lower than the 3.6 per cent annual rate found by Beenstock and Willocks (1981).

Despite the fact that some of the individual long run coefficients are not significantly estimated, the Wald-test suggests that all long run solutions (except for Paper & Printing and Households) are significant at conventional levels. Additionally, the ADF-tests[11] (except for Other Industry and Households) are significant at the 1 or 5 per cent levels, supporting the hypothesis that energy demand and its determinants are cointegrated. In order to transform the ADL models to corresponding EqCM models, it is assumed that cointegration also exists for Other Industry and Households, bearing in mind that some caveats may apply. This possible caveat is further addressed below by means of the higher power of the Kremers *et al.* (1992) procedure.

Table 3 displays estimated EqCM models that correspond to equation (4) in the preceding section. The estimated coefficients are all economically sensible with respect to the sign and magnitudes. In most cases Δy_t and either Δp_t or its lags in addition to the previous year's disequilibrium affect Δe_t. The EqCM models are all significant, as suggested by the F-tests, and y and p have positive and negative short run effects on e, respectively. Specifically, the short run activity elasticity ranges from +0.15 (Other Industry) to +0.72 (Engineering), while the short run price elasticity ranges from –0.03 (Rail Transport) to –0.22 (Chemicals). The previous year's disequilibrium has a significant negative effect on Δe_t in all cases. The coefficient's numerical value entails gradual adjustment to remaining disequilibrium and so substantial smoothing of activity and energy prices in obtaining the energy demand. In particular, the estimated adjustment coefficients range from –0.13 (Paper & Printing) to –0.90 (Iron & Steel and Non-Ferrous Metals). In other words, between 13 and 90 per cent of the adjustments to disequilibrium in the previous period take place in the current period. Finally, Table 3 reports diagnostic statistics for testing against various alternative hypothesis. These are: residual autocorrelation (General LM test), autoregressive conditional heteroscedastisity (ARCH), skewness and excess kurtosis (non-normality), non constancy in the residuals (heteroscedastisity) and misspecified functional form in the regression model (Ramsey's RESET). Ignoring the difficulties with the RESET test in some cases, the EqCM models appear well-specified, with no rejections from the tests reported.

Table 4 presents estimated EqCM models corresponding to equation (5). We notice that the models in Table 4 are identical to the models reported in Table 3, as shown analytically in Section 3. However, the standard errors of the residuals and the standard errors belonging to the

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[11] The ADF-tests are performed without an intercept to reflect the white noise properties of having a zero mean on the stochastic component of the long run solution.

individual coefficients are somewhat smaller in the EqCM models in Table 4.[12] We report estimation results of (5) for the purpose of conducting the announced Kremers *et al.* (1992) cointegration test. Critical values used in the tests are those tabulated in MacKinnon (1991).[13] The majority of the tests statistics are significant at the 10 per cent level, paralleling the conclusions from the ADF-tests that a cointegration relationship exists between energy demand and its determinants. In addition to the user Households, where no cointegration appears to be apparent as detected by the ADF-test, the Kremers' *et al.* test also suggests no stationary long run relationship for the users Power Generation and Mineral Products. However, the *t*-values are not that far from the critical values, so that cointegration may be assumed in these cases without running into too much of a danger econometrically. Besides, the relatively slow speed of adjustment towards equilibrium characterising the energy demand behaviour may also justify the assumption of presence of cointegration for the users Power Generation, Mineral Products and Households.

We have seen that both the short and long run demand elasticities vary considerably across the energy using sectors in Germany. This might be expected. As pointed out by Prosser (1985), differences in aggregation of fuels, energy sectors and countries must be expected to produce different values for the elasticities. The characteristics of each energy using sector with respect to its flexibility or lack of flexibility to change production and consumption behaviour over time might also explain the variations in the estimated elasticities. When comparing the estimated short and long run elasticities, we note that the effect of a change in income on energy demand is either smaller or greater in the short run than its long run counterparts. Both directions of the affect are equally conceivable from an economic point of view. The first would indicate that energy is a fixed input or that energy supply is inelastic in the short run. The second may follow from the fixed nature of firms' energy-using equipment in the short run. An increase in income will, thus, bring about an immediate increase in the derived demand for energy in the short term due to higher utilisation intensity of existing equipment. This derived demand is, however, reduced in the longer term as more energy efficient machines are installed. In the case of energy price effects, the estimated short run elasticity is less than the long run elasticity for the majority of the energy using sectors. This may also reflect the fixed nature of the machine and appliance stocks in that a rise in the price of energy produces a modest fall in energy consumption in the short term. Energy consumption falls further in the longer term, however, as the price increase induces the installation of more energy-efficient appliances and capital goods. This main finding echoes other studies in the literature, which find that the adjustment after the oil price shocks in the 1970s and 1980s was substitution towards less energy intensive production.

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[12] The explanation for the somewhat smaller standard errors in Table 4 compared to the ones in Table 3 is straightforward. The formula for the variance of the residuals is $\sigma^2=e'e/n-k$, where k denotes the number of estimated coefficients. Since k is reduced when estimating (5) due to imposed long run restrictions, the denominator in the formula becomes greater and the residual variance becomes smaller. The standard error of the individual coefficients is likewise affected by this smaller residual variance since $SE(\beta_i)=\sigma^2[\text{ith diagonal element of } (X'X)^{-1}]^{1/2}$.

[13] The critical values for each model are calculated on the basis of the following formula: $\beta_\infty+\beta_1/T+\beta_2/T^2$, where the β's are tabulated in MacKinnon (1991) and T denotes the number of observations in the regression. The critical values also depend on whether a time trend is included in the model.

Table 1: Estimation Results for Germany

Equation (3): $$e_t = \alpha_0 + \sum_{i=1}^{2} \alpha_{1i} e_{t-i} + \sum_{i=0}^{2} \alpha_{2i} y_{t-i} + \sum_{i=0}^{2} \alpha_{3i} p_{t-i} + \alpha_4 T + \alpha_5 D_t + \varepsilon_t ,$$

Energy using sector	Estimation period	e_{t-1}	e_{t-2}	y_t	y_{t-1}	p_t	p_{t-1}	p_{t-2}	T	R^2 F-test	Misspec. tests
1. Power Generation	1964-1993	1.312	-0.576	0.168	0.062					0.986	ok
		(0.149)*	(0.156)*	(0.173)	(0.143)					0.000*	
2. Iron & Steel	1962-1993	0.649	-0.551	0.364	-0.081		-0.247	0.196	-0.021	0.969	ok
		(0.115)*	(0.094)*	(0.102)*	(0.096)		(0.052)*	(0.058)*	(0.003)*	0.000*	
3. Non-Ferrous Metals	1962-1993	0.101		0.396	0.240		-0.157	0.065		0.987	ok
		(0.036)*		(0.128)*	(0.111)*		(0.049)*	(0.043)		0.000*	
4. Chemicals	1971-1993	0.422		0.286	-0.026		-0.257	0.215		0.812	ok
		(0.156)*		(0.208)	(0.190)		(0.055)*	(0.050)*		0.000*	
5. Mineral Products	1966-1993	0.775		0.437	-0.295		-0.155	0.145		0.955	ok
		(0.098)*		(0.236)*	(0.234)		(0.078)*	(0.075)*		0.000*	
6. Ore-extraction											
7. Food, Drink & Tobac.											
8. Tex., Cloth. & Footw.											
9. Paper & Printing	1972-1993	0.870		0.362	-0.189	-0.073	-0.010			0.972	ok
		(0.067)*		(0.290)	(0.258)	(0.074)	(0.060)			0.000*	
10. Engineering	1967-1993	0.805	-0.267	0.724	-0.345				-0.017	0.796	ok
		(0.167)*	(0.174)	(0.238)*	(0.230)				(0.007)*	0.000*	
11. Other Industry	1962-1993	0.864		0.148	-0.029	-0.067	0.001		-0.005	0.996	Ramsey
		(0.061)*		(0.159)	(0.150)	(0.037)*	(0.041)		(0.003)*	0.000*	
12. Rail Transport	1962-1993	0.879	-0.256	0.499	-0.374	-0.029	-0.087			0.886	ok
		(0.128)*	(0.182)	(0.374)	(0.343)	(0.098)	(0.102)			0.000*	
13. Road Transport											
14. Air Transport	1962-1990	0.601		0.633	0.039	-0.096	-0.095		-0.020	0.979	ok
		(0.161)*		(0.647)	(0.608)	(0.083)	(0.103)		(0.011)*	0.000*	
15. Inland Navigation											
16. Households	1964-1991	0.797		0.601	-0.534	-0.081	0.046			0.906	ok
		(0.107)*		(0.316)*	(0.304)*	(0.036)*	(0.035)			0.000*	
17. Other Final Use	1963-1993	0.470		0.348	-0.150	-0.175	-0.124	0.152	-0.0159	0.985	Ramsey
		(0.160)*		(0.192)*	(0.181)	(0.051)*	(0.065)*	(0.052)*	(0.004)*	0.000*	

Note: All estimations have been carried out by OLS. Each column shows the estimated parameters of (3) with standard errors in brackets. The R^2 and F-test statistics provided in the second last column are the coefficient of determination adjusted for degrees of freedom and the p-value associated with the significance of the regression model (excluding the constant), respectively. The column headed «Misspec. tests» includes the General LM test for serial correlation of order 2, Engle's (1982) test for 1th order *ARCH* in the residuals, test of normality due to Shenton and Bowman (1977), White's (1980) test for heteroscedasticity and Ramsey's (1969) test for misspecified functional form in the regression model. «ok» means no misspecification. «*» indicates significant at the, at least, 10 per cent level.

Table 2: Estimation Results for Germany

Equation (6): $e^s = -(\alpha_0 / \phi_1) - (\phi_2 / \phi_1)y - (\phi_3 / \phi_1)p - (\alpha_4 / \phi_1)T.$

Energy using sector	Estimation period	$-(\alpha_0/\phi_1)$	y	p	T	Wald-test	ADF-test
1. Power Generation	1964-1993	2.435 (0.819)*	0.871 (0.099)*			0.000*	-4.657^a
2. Iron & Steel	1962-1993	7.248 (0.758)*	0.313 (0.065)*	-0.056 (0.047)	-0.024 (0.002)*	0.000*	-3.781^a
3. Non-Ferrous Metals	1962-1993	1.594 (0.712)*	0.707 (0.051)*	-0.103 (0.043)*		0.000*	-4.191^a
4. Chemicals	1971-1993	5.564 (1.439)*	0.450 (0.117)*	-0.073 (0.079)		0.001*	-5.562^a
5. Mineral Products	1966-1993	2.777 (2.901)	0.632 (0.187)*	-0.046 (0.268)		0.005*	-2.984^a
6. Ore-extraction							
7. Food, Drink & Tobac.							
8. Tex., Cloth. & Footw.							
9. Paper & Printing	1972-1993	-2.178 (8.799)	1.322 (1.015)	-0.635 (0.436)		0.222	-2.565^b
10. Engineering	1967-1993	-0.593 (5.007)	0.821 (0.434)*		-0.037 (0.017)*	0.067*	-3.584^a
11. Other Industry	1962-1993	3.424 (5.963)	0.874 (0.658)	-0.490 (0.321)	-0.039 (0.014)*	0.000*	-1.854
12. Rail Transport	1962-1993	6.345 (1.112)*	0.332 (0.129)*	-0.307 (0.196)*		0.038*	-2.456^b
13. Road Transport							
14. Air Transport	1962-1990	-6.501 (5.441)	1.685 (0.601)*	-0.480 (0.192)*	-0.049 (0.011)*	0.000*	-2.104^b
15. Inland Navigation							
16. Households	1964-1991	7.491 (2.914)*	0.325 (0.211)	-0.170 (0.184)		0.646	-0.484
17. Other Final Use	1963-1993	7.322 (1.922)*	0.374 (0.146)*	-0.279 (0.098)*	-0.030 (0.005)*	0.000*	-3.166^a

Note: All estimations have been carried out by OLS. Each column shows the estimated parameters of (6) with standard errors in brackets. The Wald-test provided in the second last column is the p-value associated with the significance of the static long run solution (excluding the constant). The column headed «ADF-test» gives the t-value of the Augmented Dickey-Fuller unit root test applied on the residuals from the long run equation. Critical values used in the ADF-test are those of MacKinnon's (1991). «a» and «b» indicates stationarity, and thus a cointegrating relationship, at the 1 and 5 per cent level, respectively. «*» indicates significant at the, at least, 10 per cent level.

6. Conclusions

This paper has presented the modelling and estimation of energy demand for seventeen energy using sectors in Germany. Hence, this study adds to the rather scarce literature on disaggregated energy demand studies. We first outlined the economic background and postulated a long run equilibrium equation for energy demand with output, prices and technological progress as its determinants. Then, we applied the concept of cointegration and EqCM modelling within a single equation framework to estimate short and long run energy demand elasticities for each energy using sector. Considerable variation in both estimated long run elasticities and dynamics are found across sectors. These results may reflect important differences with regards to the extent each energy user is able to change production and consumption behaviour over time. The average long run output and price elasticities are estimated to 0.75 and –0.3, respectively. As a consequence, we may argue that CO_2 emissions from Germany are not greatly affected by energy price changes through environmental tax reforms.

It should, however, be emphasised that the empirical modelling of energy demand has been based on two simplifying assumptions; one assuming that all variables are integrated of order one and the other that output and energy prices are weakly exogenous for all parameters of interest. The latter assumption is perhaps the most critical one. Although a strong assumption, weak exogeneity implies that the cointegrating vector and the adjustment coefficient enter only the energy demand equation, so inferences about those parameters can be conducted from a conditional model of energy demand alone without loss of information. Thus, weak exogeneity permits a much simpler modelling strategy, while recognising that some caveats may apply in so doing. The results should therefore be interpreted with some caution. The Johansen multivariate cointegration method has been beyond the scope of this paper.

Finally, it should also be noticed that we have not demonstrated whether the preferred models have empirical constancy over the sample period. Hence, we recommend for future work that the statistical properties of the EqCM models should be assessed by what is not modelled, namely, the residuals. Estimation of residuals over subsamples by recursive procedures and using a battery of residual diagnostic test statistics provide a tool for investigating the stability of the coefficients in the models. A related issue that should also be investigated is the possible asymmetric nature of the energy markets in that the energy price rises of the 1970s had a greater impact than the dramatic price fall of 1986.

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